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THE PLANE-TABLE IN DETAILED GEOLOGIC MAPPING.

FREDERICK LESLIE RANSOME.

In the field equipment of the geologist, the things commonly regarded as essential are notebook, map, hammer, clinometer-compass, aneroid, hand-level, lens and some form of collecting bag or capacious pockets. This outfit is eminently portable and when it is considered that the geologist during the day's work is likely to accumulate specimens which, as the sun declines, may grow to a total weight of 25 pounds or more, that in many districts he must burden himself with a canteen and field-glasses, and that with his load he should be ready with unflagging scientific curiosity to climb ridges, descend ravines, or traverse the roughest slopes, any proposal to add to his professional impedimenta is likely to meet with ready objections. Nevertheless, it is believed that in many fields of work a plane-table may advantageously be added to the articles usually carried.

The suggestions that follow lay no claim to novelty and to some readers may appear unduly simple. Conversation with geologists, however, has shown that the plane-table is not widely used by them, and an experience of many years in the detailed geologic mapping of mining districts may yield some hints useful to younger workers and to mining engineers who have geologic problems to solve. It is not the purpose of this paper to deal with

the familiar use of the instrument in topographic mapping or in combined topographic and geologic reconnaissance. In all detailed work an accurate topographic base should be provided in advance of the geologic study, and if this is not at hand its construction is a distinct engineering problem. It is supposed then that the district is accurately mapped in contours. The methods described have been successfully used on maps ranging in scale from 1:62,500 (approximately one inch to the mile) to 1:6,000 (one inch to 500 feet) and with contour intervals from 50 to 10 feet. The larger the scale, the greater the accuracy demanded and therefore the greater the advantage of using a plane-table. Most of my own work has been done in regions of fairly strong to rugged relief and doubtless some readers of this Journal can contribute suggestions from experience in districts of difficult character. The method used, moreover, is one in which the geologist himself carries the plane-table and is independent of close assistance although of course he may oversee generally the work of assistants similarly equipped, each mapping his own part of the area. There are other methods in which an assistant operates the plane-table, keeping the geologist in sight and plotting his positions as required. It is hoped that this initial paper will call out some account, by those who have used them, of these methods also.

The form of plane-table board found most generally serviceable for geologic work is that known in the U. S. Geological Survey as the traverse plane-table. This is 15 inches square and five-eighths of an inch thick. The box compass usually attached to such a board is omitted and a small brass base-plate, threaded to take the standard screw of a camera tripod, is substituted for the heavier plate commonly used in topographical work. The board should have a good canvas case, with a flap so cut that the case can be drawn over the board, without removing the tripod, in order to protect the map against showers or in traversing undergrowth. When the tripod is detached, the board in its case can be slung under the right arm by a strap over the left shoulder and is not in the way on horse-back.

The tripod should combine strength and rigidity with as much lightness as possible. Many photographic tripods are much too flimsy for the purpose, or even for good outdoor photography. One that has successfully withstood over 10 years of hard service is made of ash strips that are from five-eighths to three quarters of an inch square in section and closes to a length of 22 inches.[1] It can then easily be carried in a case across the back of the saddle. Where the work is entirely on foot, the tripod case will be left behind and the board and tripod together be carried on the shoulder. The weight of the outfit described is between 6 and 7 pounds.

The form of alidade found most satisfactory for ordinary work is a Gurley clinometer-compass, adjustable for local declination, with 4-inch square base, 2 levelling bubbles, and 4-inch sights. This base will be a little short for some sights, but as a rule in a mining district there are sufficient objects near enough at hand to be within its reach and a near sight is generally preferable to a far one. However, a longer alidade can be carried if desired, and some workers have found the form devised by L. C. Graton to best fulfill their needs. The compass has the advantage of serving at once to orient the table, to take any necessary dips, and as alidade.

There should be added to the equipment a few small pieces of tracing-paper and three or four needles with heads of sealing wax. The most convenient way to carry these without loss is to stick them in a bit of soft rubber, such as Hartmuth H eraser, hung by a string from a convenient button-hole.

For use on the plane-table the map should be mounted on linen, although this is not absolutely necessary. A good photograph of the original drawing of the topographic sheet, printed on tough matt paper, is preferable to an engraved sheet for two reasons—the hilltops show the dots representing the topographer's

[1] The Crown No. 2 tripod, made by the Eastman company, folds to a slightly shorter bundle and has been found satisfactory for this work by some users. It has the advantage of being easily procurable.

sighting points and the lines of a photograph on suitable paper withstand erasures and hard usage better than lines produced by engraving or lithography.

The primary use of the plane-table as employed in this method is to enable the geologist to determine rapidly and accurately his own position on the map; but it has other applications, as will appear presently. He who would determine without it the position on the map of a point on some contact that he is tracing would ordinarily estimate the position with his eye after comparing the configuration of the ground with the topography of his map; perhaps check this with an aneroid reading; or, if he were still in doubt, take compass bearings on known points and plot these with a protractor—a time-consuming process with considerable chance of error. With the plane-table, however, he sets up at once, orients the map with the compass, sticks his needle into recognizable points on the map, sights on them and draws his intersecting lines—the whole process rarely consuming more than two or three minutes. It is well as a rule to choose three points rather than two as this gives a check on the result. If the map is accurate, if the points are correctly identified and if the declination set off on the compass is true for the locality, then the lines should intersect in a point. If they form a triangle larger than the allowable limit of error for the scale of the map, the cause should be investigated. The accuracy of the map may be tested by setting up on some prominent summit and orienting the sheet by bringing this point and another on the paper accurately in line with the corresponding points on the ground. Then when the edge of the alidade is placed on the map against the spot occupied and any other point, the latter should appear in the line of sight. The declination may be tested, without disturbing the setting of the table, by placing a north-south edge of the compass against a north-south line on the map and observing whether the needle then indicates true north. On those comparatively rare occasions where the compass-needle is subject to irregular local variations, the position on the map may readily

be determined by a simple graphic solution of the three-point problem. A bit of tracing paper is fastened with thumb-tacks to the board, a needle stuck approximately in its center, sights taken on three or four points and lines drawn from the needle in these directions. The piece of paper is then loosened from the board and manipulated until each line passes accurately through its corresponding point on the map. A prick of the needle through the original hole in the paper then gives the location sought on the map.

The general plan of work by this method is for the geologist to trace out his contacts, making notes and collecting necessary specimens as he goes along. At intervals, short if the contact is irregular but longer if its course is straight or simply curved, the plane-table is set up and the positions of points on the contact-line are determined. Lines of strike or other structural elements may similarly be determined by sighting along them with the alidade and drawing them directly on the oriented plane-table sheet. Experience, such as one doubtful of the advantages of the method may very easily gain for himself, has shown that an irregular contact mapped in this way is likely to present a considerably different appearance from one traced in the ordinary manner. Moreover, the greater accuracy thus obtainable often brings to light offsets or irregularities in a contact that might otherwise escape notice, and as it is easy with the plane-table to plot these features in their proper relative position they may, by their alignment, furnish the clue to important faulting. Similarly, as strike and dip can be quickly plotted on the map at numerous points of known position, it is possible as the work proceeds to detect changes of attitude of the beds, to determine with confidence the line along which a given change takes place and to formulate a working hypothesis in explanation of the observed variation.

After the plane-table has been set up and a particular location made, it is sometimes advisable to glance over the surrounding country and see whether there is not in view some contact or

other geologic feature whose position on the map may be determined wholly or in part by a sight from the point occupied. This is particularly true in districts of sparse vegetation where the geologist is traversing ridges or spurs that are transverse to the general trend of the geologic structure. In such a case it is often possible to determine not only the contacts on the spur traversed but also those on the two adjoining spurs. A few judicious sights from a ridge crest into the ravines on either side may often save the geologist some heavy climbing, provided of course that he knows the formations sufficiently well to be sure of their identity without closer inspection.

In mining districts where good underground maps are not available the plane-table supplies the geologist with a means of making fairly accurate maps of levels and tunnels with the least possible expenditure of time. At each turn in a drift the board may be quickly oriented by a back sight on the last position occupied and a map thus be constructed that is free from any possibility of error due to the attraction of steel rails, pipes, or other iron-work on the compass needle. Moreover, as the map is drawn directly on the plane-table sheet, the geological data may be plotted as the work proceeds. Large mines are generally well mapped, but even if a shaft has not been plumbed in the regular way the direction of a level may generally be determined within a small limit of error by a few careful compass readings, checked by the positions of raises to levels above.

In addition to the greater accuracy which the use of the plane-table permits and the resulting increased confidence which the geologist must feel in his map as a basis for the interpretation of structure, the user of the instrument soon learns to appreciate certain conveniences that in themselves go far to remove objections to its weight and bulk. It is no slight thing to be able to work on a flat section of a map 15 inches square, attached to a smooth board and firmly held level at a convenient height for the geologist. There are no loose corners to be fluttered at inopportune times by the wind, no fitting together of small sections or

coaxing of perverse folds, and no awkward attempts at drawing accurate lines on the unsteady foundation of hand or knee.

Finally, the plane-table, by enabling the geologist to determine his position rapidly by triangulation, supplies him with a good check on the accuracy of his topographic base and with the means of correcting at once such minor discrepancies as he may discover.

THE FORM OF SALT DEPOSITS.[1]

F. F. Hahn.

If we compare the occurrences of rock salt in the different countries, we soon come to the conclusion that with regard to the form of the deposits we must distinguish:

1. Interstratified deposits which may extend over more or less wide areas and which are interbedded with layers of clay, anhydrite, gypsum, or dolomite, sometimes in a very regular manner. The well-known deposits of rock salt in Siluric sediments of Central New York, and the Goderich Field of Canada as well as those of Permic age in Middle Germany are good examples. These occurrences, it is true, do not necessarily require marine conditions of salty sedimentation, but the primary source will be as a rule marine, the rock salt being a residue of basins at least temporarily cut off from the open sea.

2. Salt deposits which occur in lenses, patches or masses, sometimes of vast thickness, but with a very small and isolated distribution through the same horizon. As examples, the salt basins in the Keuper marl of Cheshire (England) and especially the old salt mines in the Austrian Alps (Hallstatt, Aussee, Ischl) may be mentioned which are all limited to the same lower Triassic horizon, but are separated from each other by wide areas barren of rock salt. In these cases we may think of evaporated salt lakes or swamps and an arid climate as furnishing the most favorable conditions.

As to exploitation, neither of these two kinds of salt occurrences is usually marked by extraordinary difficulties of mining and, as a rule, a general survey may enable one to decide to which class a given deposit should be referred.

[1] My acknowledgment of thanks is due to Professor A. W. Grabau, for many suggestions in the preparation of this paper.

3. Much more difficult for mining purposes, though of special economic value on account of the vast thickness of the deposits, is a third group of salt occurrences which has attracted considerable attention in the last five years. This is generally characterized by a striking irregularity of shape and by the fact that the deposits do not seem to be restricted to any definite geological horizon. Like a magmatic plug or "bysmalith" they penetrate layers which otherwise are free from salt. They appear to have fractured the overlying rocks to an important extent around the periphery of the salt mass.

F. A. v. Alberti, who introduced the term "Trias," was the first man to describe the type. In the middle of the last century, he wrote an important but almost forgotten book "Halurgic Geology" (1852) on this strange kind of salt deposits, which he named "acromorphs," viz., wart-shaped, and which we now call domes, salt domes, uplifted horsts (Aufpressungshorste)[2] or ekzema.[3]

At the present time, examples of this third type are definitely known from Louisiana and Eastern Texas, where they were described chiefly by G. D. Harris,[4, 5] and from Germany where they continue to be carefully described by a great many workers (H. Stille,[6] O. Grupe,[7] E. Harbort,[2] R. Lachmann,[3, 8, 9] etc.). Very similar occurrences are thought to exist throughout Transylvania, on both sides of the Pyrenees and in Southern Algeria, though only the first of these deposits have lately been examined

[2] E. Harbort, "Geologie der nordhannoverschen Salzhorste," *Monatsberichte Deutsch. Geologischen Gesellschaft*, 1910, p. 334.

[3] R. Lachmann, "Autoplaste Formelemente im Bau der Salzlagerstätten Norddeutschlands," *loc. cit.*, p. 114.

[4] Geological Survey of Louisiana, Bull. No. 7, Report of 1907.

[5] "Oil and Gas in Louisiana," Bull. No. 429, U. S. G. S., 1910.

[6] "Aufsteigen des Salzgebirges," *Zeitschr. prakt. Geologie*, Vol. XIX., 1911, p. 91.

[7] "Zechsteinformation und ihr Salzlager im Untergrunde des hannoverschen Eichsfelds," *Zeitschr. prakt. Geologie*, Vol. XVII., 1909, p. 185.

[8] "Salzauftrieb," *Kali*, Bd. IV., Heft 8, 9, 22–24, 1911.

[9] "Salinare Spalteneruption gegen Ekzemtheorie," *Monatsber. Deutsch. Geologischen Gesellschaft*, 1910, p. 597.

by deep drillings in a sufficiently satisfactory manner to permit general rules to be drawn from them.

Since G. D. Harris[10] has recently published in this Journal an able review of his observations made during the exploration of the Southern salt districts, I may restrict myself to a brief summary of the more important points:

The individual domes, commonly showing an elliptical outline are well characterized by quaquaversal dip and the striking fact that immediately around the salt mass, strata of upper Cretacic to Recent age are pushed up at a considerable angle, though only the newer domes along the Gulf possess a dome-shaped topography. The older ones are planed or even concaved by erosion. The core is usually made up of solid, crystalline, rock salt, while anhydrite, gypsum, and sometimes native sulphur are frequently found therewith. The horizontal extent is extremely limited, but a great vertical dimension (1,000 to 3,000 feet or more) is the rule. The domes appear to be formed "whenever conditions were favorable," even in our own times, as proved by uplifted layers with recent shells on Belle Isle, as well as by the log of a probably recent cypress tree, found at a depth of 2,643 feet below sand and salt on Petite-Anse.

Of the well-chosen plates and drawings I wish to mention particularly the cross sections of Anse-la-Butte and Belle Isle, for the sake of comparison with the following Figs. 476 to 479 (3, pp. 24, 31).

As to the North German occurrences of rock salt, one may say that to-day we have a far better knowledge than we had only three years ago when in 1907 the standard work "Deutschlands Kalibergbau"[11] made its appearance. This is due to the fact that a good deal of mining work has been carried on and a great many important borings have been made throughout the whole country between Hamburg and the Thuringian Forest and between the

[10] "Geological Occurrence of Rock Salt in Louisiana and East Texas." Vol. IV., 1909, p. 12.

[11] "Festschrift zum X. allgemeinen Deutschen Bergmannstag zu Eisenach," by F. Beyschlag, H. Everding, and others.

Russian and Holland boundary. It is the special task of the present paper to call the attention of American geologists who are interested in salt deposits to these recent results and to present a brief review of the principal German articles which unfortunately are widely scattered through the different journals. This is done with the hope that a careful correlation may be of assistance in advancing the practical investigations of salt deposits.

As a normal type of the German deposits of rock salt that of the "Stassfurt" region is always selected in which the succession of the salt-bearing members is as follows, according to H. Everding:[11]

		Feet.
At the base	Older Anhydrite of Middle Zechstein Age.	
Older succession	Older rock salt	1,000–1,600
	Polyhalite stratum	130–200
	Kieserite stratum	70–130
	Carnallite stratum	100–130
	Gray salt clay	13–33
Younger succession	Principal Anhydrite	160
	Younger rock salt	320–495
	Red salt clay	30
	Anhydrite	8
	Youngest rock salt	160
Top of Zechstein	Red clay	70–100

The Permic deposits throughout Middle and Northern Germany, however, deviate considerably from this order of succession, partly because of primary variation in the deposition and partly owing to some secondary alterations, caused by subterranean erosion, which began its work sometimes even within the upper Zechstein time and continued to the present age, and consisted of solution and local redeposition of the salty material. Thus we find that 1,900 ft. of the older succession occurs at Stassfurt, 1,200 ft. near the Kyffhäuser[12] and 30 ft. on the Eichsfeld[7] along the southern slope of the Harz.

[11] E. Fulda, "Oberflaechengestaltung in der Umgebung des Kyffhäusers," *Zeitschr. prakt. Geologie*, 1909, p. 25.

The older anhydrite at the base of the gray salt clay and the principal anhydrite between the older and younger succession may be regarded as true index horizons, though these are scarcely recognizable or are even wanting in the upper Werra Valley. Generally speaking, in the southeastern parts the "older succession" is of greater thickness and value (1,900 ft. at Stassfurt). On the east border of the upper Leine Valley only 220 ft. of the older succession balances the younger one of 300–800 ft., but even before we reach Hanover and Brunswick this same "younger succession" has thickened to 1,600 ft. It possesses a special economic value owing to the repeated intercalation of younger potash salt layers of "descendant" (secondary) origin (up to 100 ft. thickness in the case of the Aller Mines).[13]

It may be noted that the Stassfurt type contrasts strongly with the Werra type and the Hanover type. These three types, however, represent in some degree the three different types of the form of the salt occurrences in Germany.

I. The salt deposits between the Harz and the Thuringian Forest, between the Saale and the Fulda, amply prove their simple sedimentary character of origin. They are distinguished by normal interstratification and regular succession of the strata together with a lack of any considerable disturbance by tectonic movements. They lie usually, even to-day, almost horizontally. Only flat mounds and basins may be locally observed; rather frequently, however, we find a more or less strong crumpling of single salt layers, which is apparently of equal intensity in all directions, but without reference to the strata above or below the "folded" zone.

II. The second well-defined group of these German salt deposits is situated on the western and northern border of the Harz. Here a strong tectonic force was exerted with the result that steep dips, faults, and underthrusts occur, producing marked heteroplastic deformations. This is well shown by drillings and mining operations in the salt on the sharply angled slopes of

[13] K. Beck, "Untersuchung des Salzgebirges an der oberen Aller," *Zeitschr. prakt. Geologie*, 1909, p. 25.

flexures, sunken basins or "anticlinal crests (Sattelgrate)." Widening, tongue-shaped lenses, sometimes abruptly pinching out, are typical features of the interior structure, while a very important compression structure (a salt contortion—"Salz Krampf") and frequent underthrusts are characteristic for the whole deposits. Of recent observers on these deposits, I ought to mention here among others v. Koenen,[14] K. Beck,[13] G. Geinitz,[15] and R. Lachmann.[8, 8]

III. A third group with corresponding characters is represented by the salt domes of Middle and Northern Hanover and Brunswick. They extend as far as the Elbe Valley, and were brought to general notice only in very recent times. These are structurally related, in that they pierce the thick younger formations in relatively small and isolated areas, and are themselves covered by a rather thin blanket of the youngest part of the surrounding strata. The dome-like shape (Rundhorste), the distorted dipping away of those strata from the salt core, strongly remind one of the American occurrences. Here, too, a very close compression of the salt layers within the nucleus is noticeable, which frequently manifests itself by forming "head over heels" folds, that is, such as have a more or less vertical axis. The folding may go so far as to make impossible the identification of the different layers within the same salt dome, because of the strong and irregular intertwisting of the strata. Only a few hundred feet from the salt dome these strata assume again their normal position, succession and thickness over wide areas. Of course, this is combined with an impracticable depth of the Permic salt horizons.

The figures 4 to 7 are supposed to present some of the most characteristic German salt domes, which show a striking similarity to G. D. Harris' section, even in detail.

[14] "Wirkungen des Gebirgsdrucks im Untergrunde von tiefen Salzbergwerken," *Nachrichten Kgl. Gesellsch. Wissensch. Goettingen, Math.-Phys.-Klasse*, 1905, p. 17.

[15] "Salzlagerstaetten von Jessenetz," *Mitteil. Mecklenb. Geol. Landesanstalt*, Rostock, 1905, p. 1 (the place really belongs to III.).

About four miles west of Hanover the first section of the Benthe-horst[6] shows the salt mass in the midst of normal lower and middle Triassic strata. The almost vertically bedded core lies in the center of a strongly compressed anticline and has a normal series of the salt layers, but some of these intercalated beds are crumpled and the whole mass is not at all symmetrical.

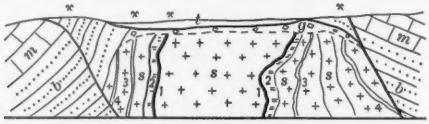


FIG. 4. Section across the Salt-dome of Benthe. Scale 1/50,000. *t*, Oligocenic-Pleistocenic; *g*, Residual gypsum; *m*, Muschel-kalk (Middle Triassic); *b*, Bunt-sandstein (Lower Triassic); *s*, Permic Rock-salt with (1) Hart-salt, (2) Principal Anhydrite and Gray Salt Clay, (3) Sylvinite, (4) Red Salt Clay.—H. Stille, *Zeitschr. für prakt. Geologie*, 1911.

It seems to have been uplifted in pre-Oligocenic time, through the normal Triassic cover which has a rather low dip. If we try to follow the axis of this anticline we find it sinking rather rapidly into the depths.

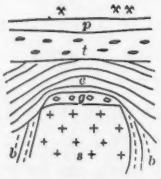


FIG. 5. Section across "Aller-Nordstern" near Verden. *p*, Pleistocenic; *t*, Tertiary; *c*, Senonic; *b*, Lower Triassic; *g*, Anhydrite; *s*, Permic Rock-salt; *A*, Tornquist.—*Industrie*, 1906 (Lachmann, Harbort).

Some distance farther to the north on the shaft "Aller Nordstern"[2,8,16] near Verden (twenty miles southeast of Bremen) we again find at a depth of 350 ft. a strongly compressed

[16] A. Tornquist, "Anschaungen ueber die Bildung der Kaliesalzlagerstätten Deutschlands," *Industrie*, 1906, Beilage, No. 14, p. 93.

anticline of rock salt apparently conformable with some lower Triassic strata. There is, however, a striking unconformity between this anticline and the overlying strata of Senonic age. Hence we are compelled to suppose a pre-Upper Cretacic period of folding of the salt core which indeed has been shown by many German authors, as a result of the last fifteen years' work to have occurred.[17]

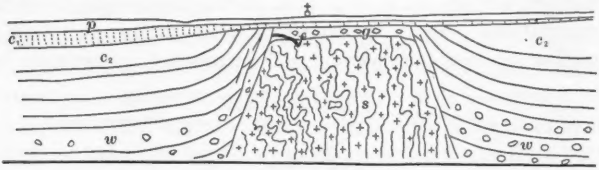


FIG. 6. Cross-section of the Rolfsbuettel Salt-dome near Brunswick. *p*, Pleistocenic; c_1, Senonic; c_2, Comanchic; *w*, Wealden; *g*, Gypsum and Anhydrite; *s*, Rock-salt with Layers of Clay, Anhydrite, Potash Salts; *B*, Basalt; E, Harbort.—*Zeitschr. Deutsch. Geolog. Gesellschaft*, 1910.

The general appearance of this mine as shown by several borings is truly dome-shaped and illustrates the close similarity of this kind of rock deposits whether occurring in Louisiana or in Middle Europe. This character likewise prevails in the section across the salt mass of Rolfsbuettel near Hillersee (thirteen miles northwest from Brunswick). Wrapped around by a relatively enormous mass of Cretacic strata of almost horizontal position, the lower part of which alone is found to have a thickness of 3,000 ft., a plug of rock salt rises up from a depth of at least 6,000 ft., without any visible connection with the regularly overlying formations. A thin Senonic mantle covers immediately both the flanking lower Cretacic and the Ekzema of rock salt which is sheltered by a pretty thick mass of residual gypsum and anhydrite. Apparently, as is the case of Fig. 6, we cannot but

[17] H. Stille, "Alter der deutschen Mittelgebirge," *Centralbl. f. Mineralogie*, Vol. 1909, p. 270, and *Jahrbuch Preuss. Geol. Landesanstalt*, Vol. 1903, p. 296; Vol. 1905, p. 103; "Mitteldeutsche Rahmenfaltung," *3d Jahesber, Niedersaechs. Geol. Vereins*, Hanover, 1910, p. 14.

be convinced that any action in pre-Senonic time has worked up the salt directly to the Senonic surface. But we observe furthermore a significant distortion and kneading of the internal structure which must frustrate any attempt at identifying the different intercalated strata.

Nevertheless, Fig. 7, taken from the shaft "Einigkeit" near Fallersleben, about 13 miles farther to the east from the last described locality, seems to increase further the complexity of the interrelations. Again we observe a very unsymmetrical steep anticline of rock salt overlain and surrounded immediately by

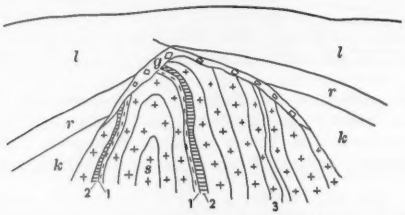


FIG. 7. Cross-section of the "Einigkeit" Salt-dome near Fallersleben. *l*, Lias; *r*, Rhaetic; *k*, Middle Keuper; *g*, Residual Gypsum; 3, Rock-salt with (1) Hart-Salt, (2) Principal Anhydrite, (3) Carnallite.—H. Stille, *Zeitschr für prakt. Geologie*, 1911.

strata of upper Triassic and Liassic age with a sharp unconformity. At this point, however, it is impossible to assume a pre-Upper-Triassic anticline covered by transgressive younger strata, since we do know without any question that there was no folding at all between Permic and Upper Triassic time in this part of Middle Europe.

Harris and Lachmann suggest that the dome-like forms of salt deposits have a wide extension over the earth. Indeed, up to date the description made by Posepny[18] of the salt mines of Transylvania, that of the Cardona salt mine in Spain, by several authors, finally that of the structure at Rhang el Melah (south-

[18] "Studien aus dem Salinargebiet Siebenbürgens," *Jahrbuch Geol. Reichsanstalt*, Wien, 1867, 1871.

ern Algeria) by the French engineer Ville[19] are, so far as we know to-day, in sufficient conformity with each other.

The peculiarities which we find again and again in all the places mentioned seem to me to require an explanation of wide applicability. Let me divide these attempts at an interpretation made by the authors up to the present time, into the following groups:

1. That a "volcanic" origin should be the first suggestion is easily understood when we consider the similarity of features of a batholith and a salt dome. Some authors looked upon the salt masses as a saliferous gypsum-magma,[19] some assumed a volcanic emanation, again the strata were thought to be tilted by the immense force of a laccolithic intrusion or at least by tremendous gas pressure. Such was the opinion of Ville in the case of the Algerian deposits, of many early writers of Germany (Leopold v. Buch, Hofmann, Karsten, before 1850) and in 1901 of A. T. Lucas, of E. Costé in 1903, and especially of L. Hager in 1904 on the American side. Indeed, it is becoming evident that at least for the Algerian deposits a close connection with propylitic, basaltic or doleritic extrusions may exist and that, furthermore, in the Pyrenees a relation to ophiolitic magma may be probable. Finally, even in Germany in several places, dikes of basalt[20] with included fragments of rock salt are observed piercing some of the salt deposits, but these seem to have a direction independent of the alignment of the salt mass and were intruded in younger time. Neither here nor in the American deposits have we at present any considerable evidence for the existence of large plutonic masses in the depths.

2. Some authors have suggested that the primary mode of deposition produced the strange phenomena. On the American side I mention Hilgard who thought in 1869 that peaks of saliferous Cretacic ridges were carved out by erosion and then covered in later time by discordant Tertiary and Pleistocenic strata. Like-

[19] "Exploration du Beni Mzab et du Sahara," Paris, 1872, p. 246, and Pomel, "Massif de Milianab," *Public. Soc. Climatol. d'Alger*, Paris, 1875.

[20] *Monatsbericht Deutsch. Geol. Gesellschaft*, No. 4, 1910, p. 340, 343.

wise on the German side Tornquist[16] proposed a salty sedimentation during lower Triassic time in northern Germany. These interpretations of the two authors were soon contradicted by the advance of knowledge of sedimentation in those regions.

Hill, in 1902, also suggested that the deposits originated in their actual shape and in their present place, but had a secondary source of material rising up from below. He was followed by W. Kennedy, while C. W. Hayes, the next year, appealed to precipitation from saturated columns of hot saline waters ascending under hydrostatic pressure. Even if this interpretation could undergo the test of physical considerations it is not available except for a very unsatisfactory portion of the deposits of debated origin and not at all for the North German occurrences.

3. In contradiction to the writers so far mentioned most of the recent German authors lay special stress on strong tectonic movements as the cause of the peculiarities of the salt domes. Likewise, in America, O. Lerch (1903) postulated anticlines of an intensive Cretacic folding below the covering mantle of younger formations. Since H. Stille has offered evidence[17] for such movements as far back as the close of Upper Triassic time and such indications for tectonic disturbances during Middle Cretacic, early Tertiary, lower Miocenic, Pliocenic and probably even Pleistocenic time had also been observed, it appears at first glance that the attempt of Stille[21] and Harbort to explain the German salt horsts as merely parts of axes of distinct anticlines, requires careful consideration. Moreover, Stille came to the conclusion that at those places where salt domes appear, a direct parting of the sedimentary ceiling ("Deckgebirge") which is characterized by a geosynclinal thickness of 18,000 to 21,000 feet of postvaristic sediments, took place, so that the compact salt sheets ("Salzgebirge"), pushed up along anticlinal lines, passed through the gap in the axis of the anticline and that only this stratum partook of the complications generally characteristic of overwhelmed geosynclines. Stille, it is true, was himself compelled

[21] "Faltung des deutsches Bodens und des Salzgebirges," *Kali*, Vol. 5, 1911, Heft 16, 17.

to take a stand against carrying the tectonic explanation to an extreme, as was done by Th. Schmierer,[22] with reference to the deposits along the upper Aller Valley, and he fully appreciates the secondary flattening of tectonic planes by subsidences over and near the "salt ekzema," caused by subterranean solution.

However modified such an explanation might become we cannot forbear suspecting that it could hardly cover all the special and general peculiarities of such dome structure, even in Germany. For the general subcircular outline of the isolated deposits, the alignment which frequently deviates widely from the common trend of normal folds and is observed not only in the internal structure of individual salt domes but also in the position of the "Ekzema-ranges" ("Reihenekzeme"), and which often shows an acute angular bending of the axis of anticlines never observed in typically folded mountain chains; and finally the type of minor as well as larger deformations within the salt core, which do not at all agree with those usually produced by normal folding movements as emphasized by Lachmann: all these points together lead us to Stille's own conclusion—that "the last word has not been said on this subject." In fact, so far as the American occurrences are concerned, an explanation of such one-sided character could not stand scrutiny, from the beginning, nor was it accepted by any of the most recent American authors.

4. Even to-day there are a few writers who are not satisfied with any of the interpretations given. They contend, and I think with convincing arguments, that all these features must find their explanations mostly in causes immediately associated with the rock salt and its physical conditions of existence, growth and solution, that is, they plead for a more or less endogenetic origin.

E. Harbort[2, 23] though starting with tectonic theories came to

[22] "Tektonik des oberen Allertals," *Monatsber. Deutsch. Geol. Gesellsch.*, 1909, p. 499, and Kirschmann, "Bau des Reihenekzems an der oberen Aller," *Geol. Rundschau*, Bd. II., 1911, p. 110.

[23] "Richard Lachmann's Salzgeschwüre," *Monatsber. Deutsch. Geol. Gesellsch.*, 1911, p. 267 (compare, too, 20).

the conclusion that the relatively plastic[24] salt mass has been squeezed upward like a fluid magma under the pressure of orogenic forces while the normally overlying strata either had been pushed aside or left behind as sluggish and inflexible masses.

On the other hand, R. Lachmann[3, 8, 9, 25] lays strong emphasis on the consideration that it is only a step from the small and apparently accessory deformations, which here and there, however, swell to a rather important total even in such undisturbed regions as the Thuringian basins, to those powerful activities which affected not only the entire salt deposit, but tended to pierce the heavy ceiling of overlying formations, and he holds that both are due to internal forces of the rock salt mass. So he introduces first: diagenetic deformations, easily recognized in the case of crumpled sheets of Kieserite; secondly, metasomatic deformations or work by redeposition of salts, *e. g.*, some carnalite zones; and finally, the factor producing the whole mode of appearance, the power of recrystallization of the salt. This he believes to include first an active process, the badly mixed salts tending to separate from each other by diffusive migration, and secondly, a more passively enforced travelling from deep regions with high hydrostatic pressure up to the plane of salt solution or the "Salt table" ("Salz-spiegel") in the region of minor stress. This salt plane as first pointed out by E. Fulda[12] in 1909, is of rather considerable stability for certain regions and presents the horizon of equilibrium between salt solution by the underground water and the rise of the salt from below (Salzauftrieb). The possibility of the salt plane to persist at a given level even during a negative phase of movements, is supposed by Lachmann to help in the formation of salt domes.

G. D. Harris supplements Hill's theory of ascending hot brines as the cause of such salt deposits by introducing the power of

[24] F. Rinne, "Umformung von Carnallit unter allseitigem Druck," *v. Koenen-Festschrift*, Stuttgart, 1907, p. 369, and "Plastische Umformung von Steinsalz und Sylvin," *Neues Jahrbuch f. Mineralogie*, 1904, I., p. 114.

[25] "Natur des Everdingschen deszendenten Hauptsalz-konglomerats," *Monatsber. Deutsch. Geol. Gesellsch.*, 1910, p. 318.

crystallization[26] as the chief factor causing the rise of salt domes. This rise is believed to be effected by rapid growth of the salt mass at the base, and occurred in the first place along the vertical axis of the cores which was subjected to the least weighting by overlying strata. Rising land would cause relative sinking of the locus of salt precipitation and results in the appearance of the salt mass at or even above the surface.

One cannot but recognize that against each of these explanatory attempts objections of considerable weight have been brought up. Harbort's theory of plastic transplantation is rendered somewhat questionable by studies in the field where the different well-known salt layers can generally be followed with great certainty, and also by physical considerations. Such an extremely plastic character of salt mixtures seems to be contrary to observed facts which indicate even some rigidity of the salt sheet in Cenozoic time. Nevertheless, at least as far as the American deposits are concerned this explanation may be applicable to some extent, provided that incontestible evidence of the existence of thick and rather pure masses of rock salt in one of the deeply situated earlier formations should be adduced. In the case of salt occurrences the material of which is evidently derived from sources of quite superficial position (Africa, Austria) I do not see any possible applicability.

The explanation by Harris must also undergo some scrutiny by the physicist in reference to the question whether in such great depths as are required, if Siluric strata furnish the salt contents, vadose waters can still become charged with dissolved salts to the required point of saturation and whether the concentration could be retained up to the place of crystallization undisturbed by underground water. Moreover, this theory is applicable only in a very limited manner to other salt deposits, not at all to those of Algeria or of Northern Germany.

[26] On the physical foundation employed by Day and Becker, "The Linear Force of Growing Crystals," *Proc. Wash. Acad. Sci.*, Vol. 7, 1905, p. 283. Compare K. Andrée, "Geolog. Bedeutung des Drucks wachsender Kristalle," *Sitzungsber. Gesell. Naturw.*, Marburg, No. 1, 1911.

The establishment on a firm physical basis of Lachmann's interpretation is certainly not yet accomplished to our satisfaction. Consequently, that author will find it necessary to bring his theory into harmony with the facts of the widely developed normal type of sedimentary succession, the regular intercalation of the potash layers forming the "annual rings," etc. His opinion is favored, however, by the fact that it seems to be the one explanation which can be satisfactorily applied to all of the questionable occurrences.

The question whether these three interpretations suffice in all the known cases of salt domes or whether a partial combination of them or even wholly different explanations are necessary for different localities, can only be decided by further comparative investigations both from the physical[27] and geological standpoint. Be that as it may, it can certainly be stated that a considerable number of significant characters are undeniably common to all salt domes now known from different regions of the world[28] and every interpreter is obviously compelled to harmonize his theories with those. I may enumerate the following characters of this type:

The more or less circular and cone-like shape and horizontally isolated situation of what is frequently a very considerable and sometimes a very pure mass of rock salt.

An apparent anticlinal structure or at least a very steep dip of the bedded salt nucleus usually with a sharp unconformity between it and the surrounding strata.

The frequency of minor deformations not conformable with the results of normal folding.

The stratigraphical independence of the deposit with reference to a certain age or certain horizon.

The secondary relationship which the salt core bears to the enclosing strata.

[27] Compare R. Goergey, "Entwicklung der Lehre von den Salz-lagerstaetten," *Geolog. Rundschau.*, Vol. 2, 1911, p. 278.

[28] In the *Geol. Mag.* (Dec. 5, Vol. 9, 23, 1912), T. C. Bosworth published an apparently closely related section across the oilfield at Bacoi after Mrazec.

The more or less active and positive rise of the salt mass piercing in some cases thick formations.

The almost unlimited time occupied by the growth of the salt domes during which eustatic movements of the earth may exert an influence on the growth of the salt domes.

The location of the present salt occurrences which is not an accidental one, but is (always?) predetermined by some tectonic movements producing crests of anticlines, fault planes, "lines of weakness" and especially crossing faults.

Exogenetic forces are not quite sufficient for a wide-reaching interpretation but endogenetic forces inherent in the salt as such must be considered.

SOME GEOLOGICAL SHORT-CUTS.

W. J. Mead.

Conversion of Rock Analyses into Terms of Minerals.

In metamorphic and petrographical work it is often necessary to translate the chemical analysis of a rock or ore into terms of minerals. The variable and complex composition of some minerals frequently make an exact translation impossible, but even in these cases it is desirable to express the approximate composition of these minerals in terms of their simpler constituent molecules. The reverse translation, from mineral to chemical composition, while probably less frequently used, is at times of equal importance.

The method most generally employed is to convert the parts by weight into molecular ratios, group these molecular ratios properly to correspond to mineral molecules, and then reconvert the molecular ratios of the minerals into parts by weight. This method is described in detail by Kemp,[1] Iddings and others,[2] and is facilitated by tables of molecular ratios the most exhaustive being those published by Osann.[3] The computations involved in this method are rather long and laborious even when aided by the tables of molecular ratios.

A more direct method in which the translation is accomplished with less computation by the use of decimal tables of mineral compositions has been published by Dr. Alfred Harker.[4] Dr.

[1] J. F. Kemp, "The Re-calculation of the Chemical Analyses of Rocks," *School of Mines Quarterly*, Vol. XXII., page 75.

[2] Iddings, Cross, Pirsson, Washington, "Quantitative Classification of Igneous Rocks," 1903.

[3] A. Osann, "Beitrage zur Chemischen Petrographie: I Molekular-quotienten zur Berechnung von Gesteinsanalyses," Stuttgart, 1903.

[4] Dr. Alfred Harker, private publication, Cambridge University Press, London, 1910.

Harker's tables, however, do not permit of the reverse translation from mineral to chemical composition and considerable repetition of tables is necessary in order that the percentage of a mineral in a rock may be calculated from any one of its constituent oxides. The principle involved is illustrated by the following single table from Dr. Harker's set of tables.

CALCITE, $CaCO_3$.

CaO	CO_2	Calc.
1	1.274	2.274
2	2.55	4.55
3	3.82	6.82
4	5.10	9.10
5	6.37	11.37
6	7.64	13.64
7	8.92	15.92
8	10.19	18.19
9	11.47	20.47

For example, if a given analysis contains 2.54 per cent. lime, in the form of calcite, the per cent. of that mineral and of the CO_2 combined in it, in terms of 100 units of rock mass are obtained from the table as follows, the operations are obvious:

2.00 CaO	requires 2.55	CO_2	and makes 4.55	calcite.
.50 CaO	requires .637	CO_2	and makes 1.137	calcite.
.04 CaO	requires .051	CO_2	and makes .091	calcite.
2.54 CaO	requires 3.24	CO_2	and makes 5.78	calcite.

A New Graphic Method.—In 1907, in connection with work in the metamorphic laboratory of the University of Wisconsin, the writer devised a set of graphic tables of mineral compositions hitherto unpublished. These tables may be illustrated by the following table, Fig. 8, for calcite. The per cent. of calcite in terms of total rock mass is indicated by divisions on the upper scale, and the corresponding percentage of the constituent oxides, CaO and CO_2, on the two lower scales. Each mineral table consists of as many scales as there are oxides in the mineral in addition to the top scale for the mineral itself. To use the table it is necessary only to read directly above the given per cent. of CaO

or CO_2 to obtain the corresponding per cent. of calcite in terms of total rock mass. Conversely the amount of the constituent oxides may be read directly below any given per cent. of calcite. For example: 5.6 per cent of CaO in a rock analysis will form 10 per cent. of calcite and requires 4.4 per cent. of CO_2.

A set of these tables for fifty-four of the common rock-forming minerals was prepared by the writer, including original and secondary minerals, both katamorphic and anamorphic. In addition to the rock-forming minerals a similar chart was prepared for the principal ore minerals for work in connection with economic geology. Thirty-seven of the principal minerals of iron, copper, lead, zinc, silver, tin, titanium, and manganese were represented.

In connection with the charts a printed form was used to tabulate the operations. In this printed form the chemical analysis is written on a horizontal line at the top of the page, as indicated, and the percentages of oxides used for each of the minerals are in turn subtracted from the total amount in the analysis, so that a balance is each time carried forward. In calculating the chemical analysis from the mineral composition of the rock or ore, the names and percentages of the minerals are written in the two columns and then the percentage of each oxide read from the chart is written in the proper line. On adding the columns for the several chemical constituents, the sums (written at the top) represent the chemical composition of the rock or ore. These tables, both for the rock and ore minerals were produced in the form of blue prints for students' use and were used to advantage both in quantitative work in metamorphism and in economic geology. An analysis could be calculated into terms of minerals much more rapidly than by the molecular ratio method and with equal accuracy.

One of the limitations of these graphic tables is the fact that to cover all possible cases each diagram should be long enough to represent 100 per cent. of the mineral. This would require that in the blue print form each diagram must be at least four feet long in order that the divisions be large enough to be prac-

FIG. 8. Graphic table for calcite.

MINERAL COMP.		CHEMICAL ANALYSIS															
Minerals	Per Cent. Wt.	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	H_2O+	TiO_2	P_2O_5	CO_2	SO_3			

FIG. 9. Blank form used in connection with graphic tables and geologist's slide rule.

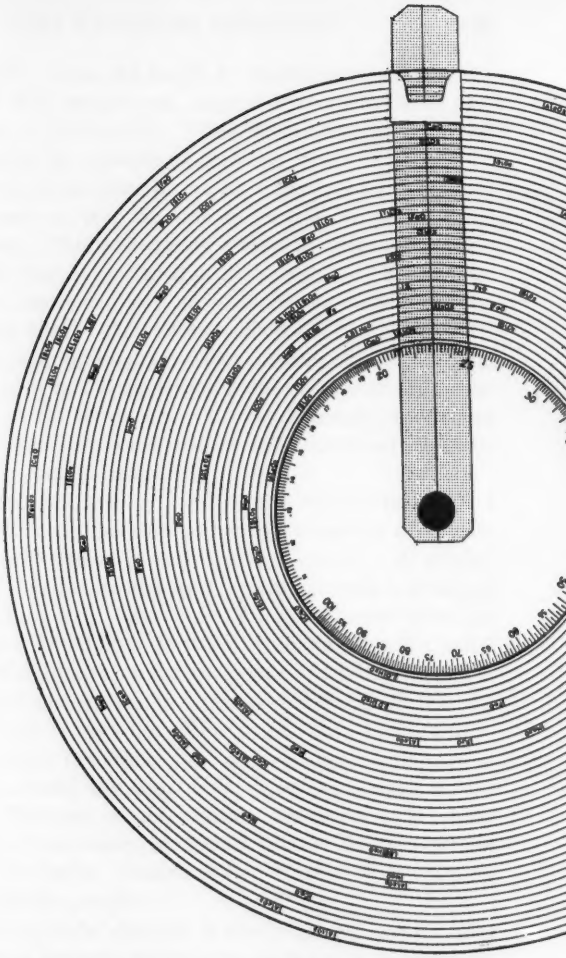


FIG. 10. Computing diagram or "geologist's slide rule" for calculating mineral

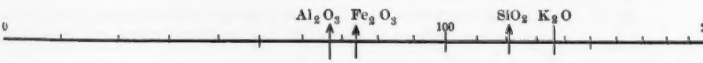
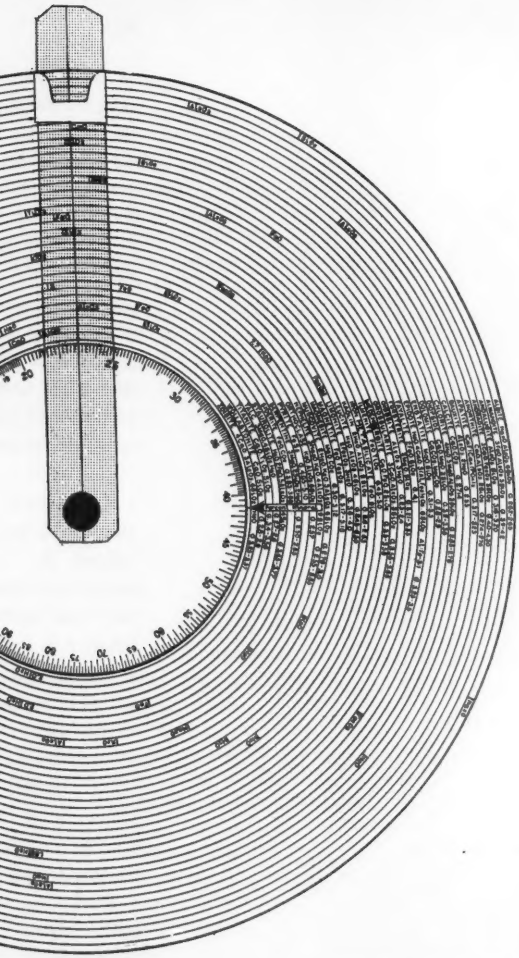
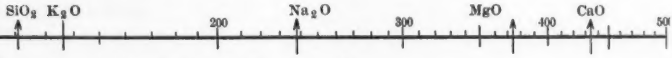


FIG. 11. Straight line diagram comparing fresh a



" for calculating mineral composition from chemical analyses and reverse.



iagram comparing fresh and altered granite.

ticable. For this reason the length of the diagram is limited to something less than 100 per cent., depending on the probable percentage of a mineral in a rock. When the per cent. of a mineral in a rock exceeds the capacity of the scale it can be handled in one of two ways, by dividing by 10, or by performing the operation in two parts so that the sum will equal the per cent. of minerals present. This is obviously somewhat awkward.

Another Method—"Geologist's Slide Rule."—These tables have now been supplanted by a more convenient method of conversion devised later. This latter method of calculation is by means of a computing diagram which involves the logarithmic principle. It is in fact a specialized form of circular slide rule. As this diagram has movable parts it is necessarily represented in a fixed position in the cut and its operation must hence be described rather than illustrated.

The diagram, illustrated by Fig. 10, consists of three parts, a disc about 8 inches in diameter containing a number of equally spaced concentric circles (one for each mineral). A smaller movable disc divided at its edge by a logarithmic scale is arranged concentric with the larger disc so that it may be turned about the common center. In addition to these two discs there is a radial transparent celluloid arm, on the under side of which a fine black line is engraved, pivoted to the center of the circles so that the black line exactly crosses the center point. The radial arm is free to move about the center and carries a slide which may be set to follow around any one of the concentric circles of the larger disc. Thirty-six of the common rock-forming minerals, both original and secondary, are included in the diagram and are arranged alphabetically. Following each mineral is its chemical formula and specific gravity.[1]

The operation of the diagram is comparatively simple. For example: given a limestone analysis containing 23.0 per cent CaO in the form of calcite, to determine the percentage of calcite in

[1] An improvement in the construction of the instrument could be made by having the logarithmic scale on a movable disc outside of the mineral circles, allowing for larger divisions and consequently greater accuracy.

the rock, and also the percentage of CO_2 combined with the CaO in that mineral, first set the slide on the celluloid arm so that the word Calcite appears just below the lower (inner) edge of the slide, then move the celluloid arm around until the black line coincides with the point on the calcite circle marked CaO. Now holding the celluloid arm in this position turn the movable circular scale, by means of the perforations, until the point 23 coincides with the black line on the celluloid arm. The percentage of calcite may now be read on the circular scale at the point indicated by the black arrow-head and is 41.1 per cent. The diagram is illustrated, Fig. 3, with its parts in this last position. The arrow-head (labeled per cent. of mineral) indicates 41.1 per cent. and the line on the radial arm indicates 23 per cent. on the small circle and passes over the point CaO on the calcite circle. The percentage of CO_2 may now be found by leaving the circular scale undisturbed and turning the celluloid arm to the point marked CO_2 on the calcite circle, reading 18.1, the percentage of CO_2, where the black line crosses the circular scale. It is convenient to use the printed form, Fig. 9, previously described, in connection with the computing diagram.

This computing diagram or "geologist's slide rule" as it may be called, makes possible the solution of practically any problem involving the compositions of the thirty-six minerals represented. Its small size and compactness makes it extremely handy. A second diagram including thirty-eight of the principal ore minerals is in preparation and it is anticipated that this will be useful in economic geology and also in metallurgy. With the two diagrams the mineral composition of an ore, including the gangue, can be computed from its analysis in a few minutes' time. The diagram has been found to be very useful not only for complete computations but for partial computations involving only one or two minerals, such as the amount of pyrite in a rock from the percentage of sulphur present, or the amount of magnesia in a limestone when only lime and CO_2 are given in the analysis.

This diagram has been used for the past two years in the meta-

morphic laboratory at the University of Wisconsin and has been found to be more rapid and satisfactory than the graphic tables previously described. A calculation of a rock into terms of minerals can be made by this means in less than one quarter of the time required for the molecular ratio method.

The "Straight Line" Method of Comparing Analyses of Fresh and Altered Rocks.

Direct comparison of analyses of fresh and altered rocks, without recalculation, may show clearly the change in composition due to alteration. The details of this change in terms of losses or additions of substances, however, can be read directly from the analyses only in cases where there has been no resultant change in mass, *i. e.*, when the addition of material balances the losses and 100 grams of fresh rock alter to 100 grams of altered rock. In most cases of metamorphic change there is an absolute change in rock mass due to losses or gains. If any one constituent is known to have remained constant in absolute amount during the alteration, the analysis of the altered rock may be recalculated to represent for each constituent the number of grams resulting from the alteration of 100 grams of fresh rock. A direct comparison of this recalculated analysis with the analysis of the fresh rock shows absolute gains and losses of constituents in terms of 100 grams of fresh rock. In cases of weathering alumina and ferric oxide are apparently most resistant to solution and afford constants against which the losses and gains of other constituents may be measured. In other types of rock alteration, such as alterations at igneous contacts, and dynamic metamorphism, where it is impossible to assume with any certainty the constancy of a constituent, a quantitative measure of the chemical change can only be made when the changes in volume, density and porosity are known. The method of comparing fresh and altered rocks by assuming some constituent to have remained constant has been widely employed by Watson, Clarke, Merrill and others and in dealing with single pairs of analyses

representing weathering, it is entirely practicable. Obviously, however, this method cannot be applied in the cases previously mentioned where no one constituent may be assumed to have remained constant.

The circular diagram method of comparing analyses employed by Leith and Harder[1] and also by Steidtmann[2] which was developed in the metamorphic laboratory at the University of Wisconsin is very effective but somewhat complicated and difficult to understand. From this circular diagram the simpler "Straight Line" method here described has been developed. This method can perhaps be best described by means of a concrete illustration of its use.

The following analyses are from Watson's "Granites and Gneisses of Georgia," page 312.

	A Fresh Granite.	*B* Decomposed Rock, 5 Feet from Surface.	*C* $\frac{\text{Fresh}}{\text{Altered}} \times 100$.
SiO_2	68.75	57.04	120.5
Al_2O_3	17.59	26.04	67.5
Fe_2O^a	1.40	1.91	73.3
MgO	.64	.17	376.0
CaO	3.25	.75	433.0
Na_2O	4.54	1.91	238.0
K_2O	3.27	2.41	136.0
H_2O+	.56	9.77	5.4

[a] All iron figured as Fe_2O_3.

The figures in the third column are obtained by dividing the per cent. of each constituent in the fresh rock by its per cent. in the altered rock and multiplying by 100. This represents then, for each constituent, the number of grams of altered rock required to contain the amount of that constituent originally present in 100 grams of fresh rock. For example: 120.5 grams of altered rock are required to contain 68.75 grams of silica, the amount present in 100 grams of the unaltered granite. If these amounts in the third column are plotted along a straight line as indicated

[1] C. K. Leith and E. C. Harder, "Iron Ores of Iron Springs Dist.," Utah, U. S. G. S. Bull. 338.

[2] Edward Steidtmann, Economic Geology, Vol. 3, page 381.

in the accompanying diagram, Fig. 10, the relative behavior of the several oxides can at once be obtained by the position of the points on the line. If any constituent is assumed to have remained constant during the alteration, all of the constituents whose points fall to the right have decreased in absolute amount and the constituents whose points fall to the left have increased. Thus, if we assume that alumina has remained constant, it is seen that 67.5 grams of altered rock have resulted from 100 grams of fresh rock and that silica, iron, magnesia, potash, soda, and lime have been lost and water gained. When lack of information makes it impossible to fix any point on the line as a constant the relative gains and losses of the constituents can be seen by the position of the points on the line. One of the chief values of the straight line diagram is the facility with which one may determine and represent the relative behavior of the several constituents from a pair of analyses representing a metamorphic change.

If, by means of density and porosity determinations (such as those employed by Ransome in Prof. Paper No. 75) the absolute change in weight is determined, the point on the straight line representing the altered phase in terms of 100 grams of the original may be indicated and the gains and losses of constituents noted by their position with respect to this point. This obviates the necessity of assuming the constancy of any constituent.

Since some of the values to be plotted on the line may be quite large, it is convenient to divide the line logarithmically as in Fig. 11, rather than in equal divisions, so that the divisions become smaller to the right of the zero point, thus giving large divisions from zero to 200, where most of the points fall and increasing the capacity of the diagram. For purposes of comparison, it is convenient to arrange a number of these straight line diagrams parallel on the same sheet of paper. In studying a number of cases of the same type of alteration, it was found advantageous to use as many horizontal lines as there are constituents and to plot all of the points for a single constituent on a separate line, thus for a number of analyses all of the points for silica can be platted on the top line, and so on, giving each constituent a sepa-

rate line. The identity of each pair of analyses may be preserved by numbering and connecting the several points for that analysis and the resulting composite diagram will consist of a number of broken lines crossing the set of horizontal lines. The slope of these connecting lines between any two constituents then becomes significant in showing which of these two has suffered the greatest relative gain or loss. Similarity in the alterations compared will be evidenced by similar slopes in the connecting line and differences by opposite slopes.

THE EFFECTS OF A BASIC IGNEOUS INTRUSION ON A LAKE SUPERIOR IRON-BEARING FORMATION.

CARL ZAPFFE.

The purpose of this article is to give the results of a microscopic and graphic investigation of the physical, mineralogical, and chemical changes involved in the alteration of the iron-bearing formation of the Gunflint district of the Lake Superior region, where the alterations have been brought about by basic igneous intrusions and in a small measure by deformation. The investigation was made to determine whether the alteration of the iron-bearing formation was a recrystallization of the substances already there, or whether the hot igneous mass was the cause of removal or introduction of constituents.

The area to which especial attention has been given in this investigation is known as the Gunflint iron district, located in northeastern Minnesota and along the International Boundary. This district is practically the eastward extension of the Mesabi Iron Range, and the westward extension of the Animikie Iron District of Canada, and is frequently spoken of as marking the place where the Mesabi and Vermilion Ranges come together. That part of the Gunflint district from which the rocks were taken for this investigation lies in T. 65 N., Rs. 4 and 5 W., Cook County, Minnesota.

In its present state the Gunflint iron-bearing formation is a type for the Lake Superior region, where such a formation has been intruded by igneous rocks. The rocks of the Gunflint iron formation are herein called cordierite-magnetite; in other districts the rocks developed under similar conditions are called amphibolitic cherts for the Mesabi range, grünerite-magnetite schists for the Marquette range, and magnetic slates for the Penokee-

Gogebic range. All differ from one another in chemical and mineral composition.

The material used for study consisted of forty carefully selected slides made from drill cores representing a complete geological section beginning with the gabbro above, then passing through the iron formation and into the greenstone below. In addition, slides were available from the United States Geological Survey, and a series belonging to Professor Alexander N. Winchell, which covered the various facies of the Duluth gabbro in Minnesota. Chemical analyses were available from a set of drill cores representing 245 feet of the iron formation in one hole, which bottomed in the greenstone, and from two 400-pound samples taken from two sections across the exposed iron formation at the surface. Earlier analyses, recorded in various publications, were also used and will be referred to.

The Geology of the Gunflint District.

The rocks are of Archean, Lower Huronian, Upper Huronian, and Keweenawan age. The Keewatin of the Archean consists mainly of basic greenstone schists. These have been described in the various Lake Superior monographs of the U. S. Geological Survey as having been derived from basalts, gabbros, diorites, and similar basic rocks. On the north and intruding the Keewatin are the Laurentian granites. Together these form the Basement Complex.

To the south and overlying the Keewatin is the Lower Huronian, not continuous throughout, and represented here by the Ogishke conglomerate and Knife Lake slates. Resting on both the Keewatin and the Lower Huronian is the Upper Huronian, represented by the Gunflint iron-bearing formation, intercalated with the Logan sills of Keweenawan age. This formation is more or less distinctly bedded, dips at various angles, due in part to moderate cross folding, but essentially inclined southward at an average of 45°. The strike is a trifle north of east and south of west. Due to extensive metamorphism, this formation

has lost nearly all of its original characteristics and assumed others which are the basis of this study. The rocks are now hard, dense, recrystallized, more or less magnetic, dehydrated, and rich enough in iron in places to be of value as an ore.

Overlying all these formations is a large mass of gabbroid rocks of Keweenawan age and known as the Duluth gabbro. Except for a few acid intrusives, this mass consists of a variety of basic rocks of a gabbroid nature in thick beds dipping southward. The Duluth gabbro is intrusive into the older rocks as a large boss, but sills thereof intrude the iron formation and are commonly known as the Logan sills. It is this mass of gabbroid rocks that has caused the metamorphism of the older rocks in the Gunflint district, and it is itself endomorphosed where in contact with them.

The greater ease with which the iron-bearing formation rocks have weathered has caused a swampy low land between the greenstone ridge on the north and the gabbroid mass on the south. The greenstones stand boldly with steep north faces; the gently southward dipping gabbro mass and the sills have crumbled away but slowly and in such a manner that a characteristic saw-toothed topography has resulted.

The Keewatin Greenstones.

The Keewatin greenstones in the Gunflint district present as a whole the same features as in other parts of the region. They are ellipsoidal and very schistose. Clements[1] refers to them for this district as metadolerites and metabasalts. They are dark green to black in color, variable in grain, and frequently show an ophitic texture.

Immediately below the Gunflint iron-bearing formation these greenstones have been metamorphosed by the Keweenawan rocks, presumably at the same time that the other formations were thus effected, to such an extent that their texture now is granular and

[1] "The Vermilion Iron-bearing District of Minnesota," by J. M. Clements, Mon. U. S. Geol. Survey, Vol. 45.

poikilitic, the rocks are of lighter shades, frequently vitreous, dense and very tough. Where weathered, the cordierite has suffered severely and the rock has changed in color to a rusty brown.

The specific gravity of the basic greenstones is usually about 2.90 to 3.00. The mineral specific gravity of the metamorphosed greenstone was calculated from the minerals in the slides and found to be 3.015; the rock specific gravity, determined by the pycnometer method, was found to be 3.000. No calculations were made of the pore space, but judging from the compactness of the rock and its similarity in this respect to the others in this study and for which the pore space was calculated, it is safe to assume that it is practically nil.

The mineral composition of this mass is shown in the table on page 175, and the one striking thing is the simplicity of the average composition, being essentially cordierite and hypersthene; in some slides biotite was also very important. These minerals, together with the poikilitic texture, are a certain indication of the metamorphic character of the rock. In some slides the cordierite occupies about 70 per cent. of the slide. It is well twinned, and includes numerous small staurolite prisms in a regularly oriented position which is a very distinctive feature. The hypersthene has a worm-eaten appearance with small rounded biotite inclusions and with well-formed and fresh biotite around it. Some of the biotite flakes have inclusions of small zircons which give pleochroic halos in the biotite. Some epidote was noticed. Magnetite and pyrite were practically absent. Brownish-green hornblende has been observed by others in slides of this same horizon but outside of this area studied. Cordierite has not been reported and it seems it has been overlooked. It greatly resembles the acidic plagioclase feldspar when these are not twinned, and these are reported in connection with these same slides. Cordierite is also very much like quartz and when the former is not twinned, the uni-axial character of the latter is usually the only safe distinction. In the hand specimen this mineral has been mistaken repeatedly for quartz.

The large amount of hypersthene is a ready means for dis-

tinguishing rocks from this horizon. When it occurs at any other place it is not so abundant, and though the other orthorhombic pyroxenes may be present, it is then usually the mineral bronzite.

No analyses were made of this rock, but the constituent minerals indicate that the silica, alumina, and magnesia are the important elements, that the iron and potassium are low, and that calcium and sodium are practically lacking.

The chemical composition of the average basic greenstone was approximated by averaging all of the basic greenstone analyses available in the various reports on the Lake Superior districts where the information was such that no seriously altered rock might be included. Twenty-two analyses were averaged; they were obtained from the following districts: Menominee (11), Marquette (7), and Vermilion (4), and the result is shown in the following table.

AVERAGE CHEMICAL COMPOSITION OF THE BASIC KEEWATIN GREENSTONES.

	Per Cent.
SiO_2	52.46
Al_2O_3	16.77
Fe_2O_3	3.92
FeO	5.44
MgO	5.20
CaO	6.23
Na_2O	2.58
K_2O	1.39
H_2O —	3.28
TiO_2	0.45
P_2O_5	0.16
CO_2	2.14
	100.00

(Total SO_3, MnO and BaO less than 0.05 per cent.)

Comparing this average analysis with that obtained for the average Keweenawan mass (page 155), it will be observed that the two are strikingly similar.

The Iron-Bearing Formation.

The Gunflint iron-bearing formation contains two distinct phases, namely (1) the cordierite-magnetite rock forming the bulk of the formation, and (2) a contact phase. In this area there is a ten or fifteen foot layer of the cordierite-magnetite rock, more or less continuous, at the bottom of the iron formation, which can be used as an ore of iron (see Fig. 12).

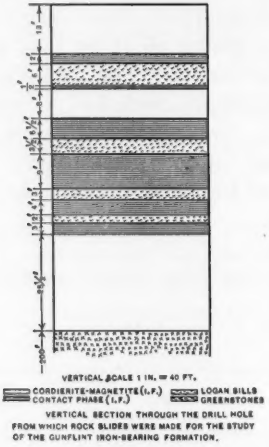

VERTICAL SCALE 1 IN. = 40 FT.
CORDIERITE-MAGNETITE (I.F.)
CONTACT PHASE (I.F.)
LOGAN SILLS
GREENSTONES
VERTICAL SECTION THROUGH THE DRILL HOLE FROM WHICH ROCK SLIDES WERE MADE FOR THE STUDY OF THE GUNFLINT IRON-BEARING FORMATION.

Fig. 12.

Where the iron-bearing formation is in contact with the sills, there a narrow band of the former contains minerals which make it difficult to distinguish the iron-bearing formation from the sills which are themselves very different in mineral composition from the normal types of the Keweenawan mass. This band of the iron-bearing formation will therefore be referred to as the "contact phase," while the balance of the formation will be referred to as the "iron-bearing formation."

The rocks vary from dark green to black in color and from fine to medium grain in texture. They are poikilitic, occasionally

presenting banded structures due to a segregation of like colored minerals. The ores are sometimes very coarse grained. The rocks are dense and very tough. The pore space is less than one per cent. and in most cases nil. Samples were selected from a hole, which bottomed in greenstones, representing 245 feet of the iron formation; the material was pulverized, and the specific gravity determined by the pycnometer method proved to be 3.620. The mineral specific gravity calculated for the same from the petrographic determinations of the proportions of minerals present was 3.618. The mineral specific gravity calculated for the ore was 4.147; the actual determination was 4.080. The mineral specific gravity calculated for the contact phase was 3.321, but no actual determinations were made of it.

The mineral compositions of the iron-bearing formation, the contact phase, and the ores alone, are shown in the tables on pages 175 and 176. The rocks have frequently been referred to under the name of "cordierite-norite," and "silico-ferrolyte" when richer in iron. The term "cordierite-norite" will be reserved for the metamorphosed gabbroid rocks to which it better applies, and as "silico-ferrolyte" implies a rock richer in iron and quartz, it will be replaced by the simple name "cordierite-magnetite" which better expresses the nature of the iron formation.

The ore is readily distinguished from all other rocks by its high content of fayalite. The iron formation outside of the contacts is readily distinguished by its large amounts of fayalite and fairly large amounts of hedenbergite, of hedenbergite and bronzite together, or bronzite without feldspars. The contact phases have large amounts of quartz or pyrrhotite. In addition, certain minerals present only in small amounts are characteristic of these various phases, for example:

Iron Formation.—Quartz 2 per cent., grünerite 1 per cent., pleonaste 0.02 per cent. (not noted throughout) and small quantities of the many other minerals considered together, as apatite, rutile needles, hornblende 2.90 per cent., biotite 2.5 per cent.,

diopside 2.8 per cent., augite 4.5 per cent., hypersthene 2.5 per cent., and diallage 0.50 per cent.

The minerals are xenomorphic and include each other with no regularity. As a whole they are fresh and where they have been effected by weathering, the alterations have progressed but very little. This has a bearing on the commercial value of the formation; being made up of refractory minerals, it is not to be expected that secondary alterations have done much toward concentrating the iron into commercial deposits.

The slides showed apatite and titanium-bearing minerals in very small quantities and those only in the contact phase. Pyrrhotite was present in variable amounts throughout, frequently up to 10 per cent., and in some places as high as 35 per cent. These high values are characteristic of the contact phases. Quartz, the mineral usually common in other Lake Superior iron-bearing formations, is present in a concentrated manner only in the contact phases, where there is also a large amount of the ferromagnesian silicates; elsewhere quartz is present only in small amounts. It is always coarsely crystallized. Magnetite is concentrated to some extent at the bottom of the iron formation, and with it is the heavy iron-bearing olivine called fayalite. Cordierite, heretofore rarely noted in abundance the world over, is the most conspicuous mineral in the entire series, often forming 50 per cent. of a slide. Its perfect pseudo-hexagonal twinning and characteristic staurolite inclusions, which are oriented in a definite manner with respect to the optic directions of the cordierite, are notable and distinguishing features.

The close association of the fayalite with quartz, magnetite, and cordierite, tends greatly towards explaining the nature of the metamorphism which the original iron-bearing formation has undergone. Besides the abundant mineral inclusions giving the poikilitic texture, there are large quantities of gas and liquid inclusions.

Only two analyses of the Gunflint iron-bearing formation are available. The one is from the same drill hole previously mentioned, and the other from two four hundred pound samples

taken from across the exposed surface of the iron-bearing formation. They are as follows:

ANALYSES OF GUNFLINT IRON-BEARING FORMATION.

No. 1, core, analysis by Lerch Bros., Virginia, Minn.
No. 2, surface, analysis by Dickman & MacKenzie, Chicago.

	No. 1, Per Cent.	No. 2, Per Cent.	Average, Per Cent.
SiO_2	63.32	57.70	60.51
Al_2O_3	1.46	0.95	1.20
Fe	23.95	26.50	25.22
MgO	0.32	0.72	0.52
CaO	0.19	1.16	0.67
Na_2O	None	?	0.00
K_2O	"	?	0.00
H_2O	Small or none	Small	Small
P_2O_5	0.09	?	0.03
S	0.968	?	0.59
MnO_2	0.63	1.31	0.92
Increase in weight due to oxidation of ferrous iron on ignition	1.13		
Ignition loss		0.20 (S?)	

Repeated tests for TiO_2 on other drill cores showed but a trace, if any.

The core sample give a more accurate analysis of the iron-bearing formation it seems, because of the difficulty which arises when taking surface samples in distinguishing between iron formation and the small intrusive sills. In the surface sample a slightly larger amount of calcium and magnesium should therefore be expected because of the ferro-magnesian minerals in the sills.

THE KEWEENAWAN ROCKS.

The Keweenawan rocks overlie the iron-bearing formation to the south and intrude it as sills. The sills are known as the Logan sills and are of wide extent in this region. In the section studied there are four sills (see Fig. 12), the thickest being 6 feet and the thinnest 2 feet, the four totalling 14½ feet. They are so completely endomorphosed that they bear little or no resemblance to the parent gabbro mass and are distinguished with difficulty from the Gunflint iron-bearing formation. Imme-

diately overlying the iron-bearing formation, and to the south, there is an uneven but rather continuous layer of endomorphosed gabbroid rocks, not altered enough to make its identification difficult, but sufficiently so to indicate that undoubtedly this contact phase developed contemporaneously with the metamorphism of the iron-bearing formation when the two came in contact with each other at the time of the intrusion by the former. This portion of the gabbroid mass will be referred to as the "contact phase of the gabbro." Stratigraphically above this, and to the south in this area, is the main mass of gabbroid rocks which is commonly known as the Duluth gabbro. These three divisions will be considered separately.

The Duluth gabbro is composed of a variety of basic igneous rocks. These have been studied in great detail by Professor A. N. Winchell.[1] The names by which these varieties are known are as follows: Olivine gabbro, olivine diabase, normal diabase, quartz gabbro, orthoclase gabbro, plagioclasyte, troctolyte, cordierite-norite, and titaniferous magnetites. The first three alone are important, and the last two represent extreme variations from the normal mass.

It is apparent that a variety of colors exists with so many facies to a mass, but considering only the important facies, the colors are prevailingly greenish-grays to almost black. The rocks are granitic and ophitic, and finely to coarsely crystalline. The important minerals are usually readily distinguished in the hand specimen.

In order to obtain an idea as to what the composition of the original igneous magma might have been, it was necessary to obtain analyses for the different facies and weight these values according to the relative importance of the respective facies in the entire mass. They were weighed as follows: 20 olivine gabbros, 20 olivine diabases, 10 normal diabases, 1 each of the plagioclasytes, troctolytes, and quartz gabbros. The resulting

[1] "Mineralogical and Petrographic Study of the Gabbroid Rocks of Minnesota," by A. N. Winchell, AM. GEOL., Vol. XXVI., 1900, pp. 151–188, 197–245, 261–306, 348–388.

average corresponded very closely to that of the olivine diabase. The composition of the mass is shown in the following table.

AVERAGE CHEMICAL COMPOSITION OF THE BASIC KEWEENAWAN ROCKS.

	Per Cent.
SiO_2	48.23
Al_2O_3	18.12
Fe_2O_3	2.88
FeO	8.46
MgO	6.28
CaO	9.32
Na_2O	2.80
K_2O	0.57
H_2O —	1.61
TiO_2	1.00
P_2O_5	0.12
CO_2	0.39
MnO_2	0.15
NiO_2	0.07
	100.00

From this average analysis the "Norm" was calculated according to the Iddings method, and the mass was found to correspond to the variety known as "hessose."

"NORM," AVERAGE KEWEENAWAN MASS.

Mineral.	Per Cent.
Orthoclase	3.34
Albite	25.20
Anorthite	35.05
Diopside	8.52
Hypersthene	15.01
Olivine	6.19
Magnetite	4.18
Ilmenite	1.98
Apatite	0.31
Etc.	0.21

Since the average chemical composition agreed with that of an olivine diabase, the average mineral composition was assumed as approximating that of this type of rock as found in this mass, allowing for the small amounts of miscellaneous minerals which would enter due to the less common types. Several minerals dis-

tinguish this facie from the others, namely, hyalosiderite (or possibly even the chrysotile), or titaniferous diopside,[1] or the very large amount of feldspars. Table No. VI. on page 177, shows the mineral composition.

The specific gravity of the Duluth gabbro was calculated in the same manner as the chemical composition and was found to be 2.920, and that of the olivine diabase examined and analyzed was 2.910. The mineral specific gravity of this average mass, calculated from the minerals of the olivine diabase, was found to be 3.05.

The slides of the contact phase of the Duluth gabbro examined are from cores that are very similar in color and texture to the greenish-gray olivine gabbros and diabases of the main mass of the Duluth gabbro. Some are more vitreous than others, due to the development of new minerals, especially cordierite. This has made the rock denser than the parent mass and therefore its specific gravity is higher. This was calculated from the mineral composition and found to be 3.295 while the original, the Duluth gabbro, was calculated to be 3.05, the rocks themselves giving only 2.92. The greater refractoriness of this rock is shown by the smaller amount of alteration products.

Table VII. on page 178, shows that this horizon has not so simple a mineral composition as the main mass of the Duluth gabbro, but is itself far simpler than the Logan sills shown in Table No. V., on page 177. Perthite, or large amounts of bronzite and perthite, or bronzite and feldspars are combinations which readily spot this phase of the Keweenawan rocks. A small amount of chrysolite (2 per cent.), zircon and epidote, and a comparatively large amount of sphene and ilmenite (1.90 per cent.) are also distinctive features.

A description is given of the perthite, as the significance of the mineral in this problem is not entirely understood and may be

[1] This diopside is fully described by Winchell (*op. cit.*), who calls it "pigeonite." It differs from previously described diopsides in that the optic angle is prevailingly quite small, but there are gradational values up to that of the normal diopside. It differs chemically in that the calcium is low, the magnesia increasing accordingly.

questioned. Two slides taken 32 feet apart in the same drill hole show a large and beautiful development of perthitic intergrowth. It presents many beautiful forms and arrangements of inclusions. These inclusions themselves vary in composition, shape and arrangements in the different crystals, but not in an individual one. In the case of an individual crystal the inclusions are somewhat definitely oriented with respect to that crystal. These inclusions are of liquids, gases, rod-shaped bronzite, and others not determined. They lie in a feldspathic groundmass whose index is lower than that of the surrounding labradorite. The perthite is found persistently associated with olivine, even included by the same like any ordinary mineral. When surrounding an olivine crystal, the two are usually separated from one another by a thin rim of pyroxene. Biotite is a favorite associated mineral. There is a sharp line of separation between the perthite and the other plagioclase feldspar.

Very little has been written regarding perthite, or perthitic intergrowth. Mann[1] considers it likely to be evidence of zonal growth. Kloos[2] studied perthite from Baikal Sea, Siberia, and finds it to consist of three distinct feldspars. Two are like twinning lamellæ crossing nearly at right angles and thus cause a mesh appearance.

The third is inlaid in irregular strips. The first two are a mixture of microcline and oligoclase, the third an albite, with the oligoclase content prevailing. The orthoclase content is therefore less than one half. Analyses given were as follows:

ANALYSES OF PERTHITE.

	I.	II.	III.
SiO_2	64.83		65.52
Al_2O_3	22.04	21.46	24.95
CaO	1.38	1.72	2.43
K_2O	7.27	6.53	....
Na_2O	4.03	3.94	7.10
H_2O	0.31		
Total	95.80	33.65	100.00

[1] Mann, "Neues Jahrbuch für Mineralogie," p. 389, 1879.
[2] Kloos, *ibid.*, Vol. 11, 1884, p. 89.

The bronzite and the cordierite alone are deemed sufficient to mark the metamorphic effects on the gabbroid mass, zircon and epidote certainly do, and the fact that the perthite is so abundant and also contains bronzite inclusions is perhaps additional evidence.

There are no analyses for any of the cores of this contact phase of the gabbro, but an examination of the minerals, compared to those of the rocks of the main mass of the Duluth gabbro, indicates that there probably was a large introduction or concentration of sulphur, some potassium, and perhaps magnesia, and that the titanium of the diopside separated to form ilmenite (and titanite), while the other elements most likely readjusted themselves to some extent to form new minerals. Carbon dioxide and water, present in small amounts only if at all, were quite certainly driven off and represent perhaps the only loss of constituents, unless it be calcium and sodium. Since it has been observed that there is a strong tendency for segregation of certain minerals, it is possible that the losses and introductions enumerated hold only for a very small volume of rock, and in an immediately adjacent volume a different chemical and mineral composition may exist.

The Logan Sills.

The Logan sills in the section studied are only of small dimensions and therefore are metamorphosed throughout their width. In the field there are some of larger dimensions, which are less metamorphosed, judging from petrographic descriptions, and have been referred to as dolerites.[1] In the older publications of the Minnesota Geological and Natural History Survey the rocks of the sills have been termed "muscovadoes," meaning "sugary brown" and referring to the peculiar rusty color on the weathered rock surface. The rock described by A. N. Winchell[2] as "cordierite-norite," and as being a facie of the Duluth gabbro, corresponds to the composition of the rocks in the slides of the sills

[1] Clements, J. M., *op. cit.*
[2] Winchell, A. N., *op. cit.*

studied; the term will therefore be used to distinguish them from the other types in this district.

The rocks forming these sills are normally dark-colored; the grain varies with the size of the sill and the textures are finely granitic and aphanitic. Some porphyritic specimens have been reported in the field, while under the microscope many are found to be poikilitic. The rocks are often glassy due to the abundance of cordierite, and are then dense and very tough. Their mineral specific gravity has been calculated to be 3.222, which is higher than that of the foregoing mentioned gabbroid rocks.

The mineral composition of the sills is shown in Table No. V., on page 177. The variety of the minerals is striking. Physically the sills often resemble the iron formation contact phase very much, and it is difficult to tell where the one begins and the other ends. Under the microscope the presence of the feldspars or the quartz solves the question at once. The distinctive minerals of the sills are the large amounts of hornblende, or augite, or biotite, and when compared to the rocks of the parent gabbro mass the smaller amount of feldspar is sufficient, though in most cases the feldspar is present in larger amounts than either of the three minerals mentioned. The small amounts of apatite (0.15 per cent.), epidote (0.05 per cent.), diallage (0.62 per cent.), and hyalosiderite (1.90 per cent.), are of material aid in making further distinctions.

Compared to the main mass of the Duluth gabbro, a very marked change has taken place in the mineral composition. In the gabbro the plagioclase is the most important mineral; in the cordierite-norite it is sometimes lacking, or only present as an accessory mineral, and then more acidic. In the same manner the olivine decreases in amount and becomes more ferriferous. The monoclinic pyroxenes are replaced in part or entirely by the orthorhombic varieties. The biotite, which is rare in the gabbro, except as an alteration product, becomes an important constituent and is quite certainly a product of recrystallization.

No analyses were made of any of the samples studied, but the

cordierite-norite described by Winchell[1] corresponds to a rock taken, it seems, from a place where the specimen may be considered as representing the exact contact with the iron-bearing formation because it contains both feldspar and quartz. This is the only analysis available, but it will serve to suggest the chemical composition of the rocks at this horizon, but as this rock type varies widely in short distances, no great weight can be placed on the apparent changes suggested by this one analysis.

ANALYSIS OF CORDIERITE-NORITE.

	Per Cent.
SiO_2	52.84
Al_2O_3	23.62
Fe_2O_3	0.65
FeO	10.00
MgO	3.16
CaO	3.92
Na_2O	2.64
K_2O	0.67
H_2O	1.87
TiO_2	Trace
Mn	0.18
BaO and S_2O	.....
Total	99.80

THE ORIGINAL CHARACTER OF THE GUNFLINT IRON-BEARING FORMATION.

What was the original character of the Gunflint iron-bearing formation at the time of the igneous intrusion? Was it a ferrous carbonate, or silicate, or, was the iron in the ferric state in the form of the ferruginous cherts or slates, or, was it a combination of these rocks? It is from these rock types that the ores of the other Lake Superior districts have developed.

In the introductory remarks it was stated that the Gunflint district was practically an eastward continuation of the Mesabi Range and a westward continuation of the Animikie district. The structure of the three districts is simple and similar, and though the iron-bearing formation of the Gunflint district has been severely anamorphosed, some lithological likenesses to the

[1] Winchell, A. N., *op. cit.*, p. 376.

same formation of the other districts are still to be observed. There seems to be sufficient evidence that the cordierite-magnetite rock of the Gunflint district was originally in part a cherty and pyritic iron carbonate, in part a ferrous silicate like the Mesabi greenalite rock, and to some extent the ferruginous slates.

Clements[1] in his monograph on the Vermilion range, states that the rocks of the Gunflint iron-bearing formation commonly have structural features indicating their development from ferrous silicate granules. He also states: "One finds cherty ferruginous rocks, which, when examined under the microscope, are of interest since they show the relationship of these rocks to the less altered normal rocks of the iron-bearing formation of the Mesabi range, etc." No analyses for rocks exhibiting this granular texture are available.

Clements further reports finding ferrous carbonate rocks about Gunflint Lake. The average of the three analyses given in his monograph, together with that of the iron formation as given hereinbefore and those of the original and altered iron-bearing formations of the Mesabi and Penokee-Gogebic ranges, is given in the following table:

AVERAGE ANALYSES OF GUNFLINT CORDIERITE-MAGNETITE, MESABI TACONITE, AND PENOKEE-GOGEBIC FERRUGINOUS CHERT.

	Average Gunflint Cordierite-magnetite.	Average Mesabi Taconite.[a]	Average Penokee-Gogebic Ferruginous Chert.[a]
SiO_2	60.51	58.70	53.11
Al_2O_3	1.20	0.54	1.32
Fe	25.22	25.70	28.76
MgO	0.52	0.89	....
CaO	0.67	0.13	0.25
Na_2O	None	None	None
K_2O	None	None	None
H_2O	Small	1.96	1.66
P_2O_5	0.05	0.04	0.092
S	0.59	Trace	Trace
MnO	0.92	Trace	Trace
TiO_2	None	None	None

[a] Analyses for the average taconite, greenalite and ferruginous cherts are from the U. S. Geol. Survey monograph on the Lake Superior region (in preparation).

[1] "The Vermilion Iron-Bearing District of Minnesota," by J. Morgan Clements, Mon. U. S. Geol. Survey, Vol. 45, pp. 374–385.

AVERAGE ANALYSES OF GUNFLINT FERROUS CARBONATE, MESABI FERROUS SILICATE (GREENALITE), AND PENOKEE-GOGEBIC FERROUS CARBONATE.

	Average Gunflint Ferrous Carbonate.	Average Mesabi Ferrous Silicate (Greenalite).[a]	Average Penokee-Gogebic Ferrous Carbonate.
SiO_2	42.89	55.80	41.15
Al_2O_3	0.12	0.48	1.53
Fe_2O_3	2.03	10.45	?
FeO	18.45	23.20	?
Fe	15.87	25.17	24.51
MgO	7.07	4.20	3.76
CaO	8.16	0.08	0.86
H_2O	1.45	5.83	1.18
TiO_2	Trace	....	....
P	0.0394	0.012	0.026
CO	19.20	....	14.10
FeS	0.13	....	....
MnO	0.25	....	....
Total	99.789	100.05	

[a] Analyses for the average taconite, greenalite and ferruginous cherts are from the U. S. Geol. Survey monograph on the Lake Superior region (in preparation).

From these analyses it is to be observed that the cordierite-magnetite and the taconite are very similar.

A constant relationship exists throughout between the ratio of the silica and the metallic iron content of the original or the altered iron-bearing formation rocks for the following districts, for example:

Per Cent.

Gunflint:

Magnetite rock, Silica = 60.51
Fe = 25.22 Fe : Silica : : 1 : 2.371.

Carbonate rock, Silica = 42.89
Fe = 15.87 Fe : Silica : : 1 : 2.717.

Mesabi:

Taconite, Silica = 58.70
Fe = 27.70 Fe : Silica : : 1 : 2.284.

Greenalite, Silica = 55.80
Fe = 25.17 Fe : Silica : : 1 : 2.215.

Penokee:

Ferruginous chert, Silica = 53.11
Fe = 28.76 Fe : Silica : : 1 : 1.777.

Carbonate rock, Silica = 41.15
Fe = 24.51 Fe : Silica : : 1 : 1.679.

The significance of this constant ratio is explained as follows:

It has recently been shown in the laboratory at the University of Wisconsin that when a unity volume of the original greenalite or cherty iron carbonate alters to ore, the per cent. of metallic iron remains practically the same, silica is leached out, and the per cent. of volume apparently lost but representing the difference between the original and the final volumes can be accounted for by the pore space and the slumping developed. Further, that the sum of the per cent. of metallic iron and silica by weight is quite constant in all specimens irrespective of the stage of alteration. These conditions are practically alike for both the Mesabi and Penokee-Gogebic ranges. In the average analyses of these successive altered stages of the iron-bearing rocks the ratio of the per cent. by weight of the metallic iron and the silica ought then to be constant, or nearly so, and that is what is shown by the above figures. This same relation is found to hold for the same constituents of the Gunflint iron-bearing formation, and signifies that the latter, prior to its metamorphism, had in part characteristics quite in accord with similar formations of the Mesabi and Penokee-Gogebic ranges, namely, those of the ferrous silicate or the greenalite rock, and the ferrous carbonate rock.

Although there is this striking similarity in the chemical composition, there is absolutely no similarity in the mineral composition or the physical characteristics of the cordierite-magnetite and taconite. They have but one mineral in common and that is the quartz, and in the Gunflint district it is present in large amounts only at the contacts with the sills. The minerals are further of an entirely different class, the one, secondary products due to katamorphism, the other secondary due to anamorphism.

That the original formation was rich in sulphur can be surmised from the analyses of these ferrous carbonates (see page 162), which show that in each sample the sulphur was present in amounts of about 0.12 per cent., and these samples were not selected to show a sulphur content. Further, the analyses of the iron-bearing formation in its present state are very high in sulphur due to the pyrrhotite content. One is apt to think at once that perhaps this sulphur had been introduced by the intruding

igneous masses causing the metamorphism, especially so because the mineral pyrrhotite has always been supposed to be a mineral characteristic of a gabbroid rock rather than of an iron-bearing formation of sedimentary origin, and in the Lake Superior region valuable ore deposits, other than iron, are found closely associated with pyrrhotite and in this same mass of gabbroid rocks.

In the series under consideration, the occurrence of pyrrhotite in the iron formation has more weight regarding its source than is at first apparent. The greatest amount of this mineral is found in a layer of rocks lying immediately above the richest part, at the bottom, of the iron formation. This sulphide-bearing layer consists of seven feet of iron formation intercalated with two sills amounting to five feet in thickness. In these twelve feet the pyrrhotite averages 14 per cent., and in one slide runs as high as 35 per cent. Higher in the iron formation only small amounts are found here and there. The metamorphosed gabbro lying above the iron formation contains this mineral only in its upper parts. The various facies of the unmetamorphosed Duluth gabbro described by Winchell[1] contain only a minute amount of pyrite, and in the calculation of the chemical composition for the average mass the sulphur content was a negligible amount. The situation is, therefore, one where the sulphide mineral is located toward the bottom of the iron formation; in the metamorphosed gabbro mass it is near the top; and in the original and unmetamorphosed gabbro mass it is barely noticeable.

The following facts are taken to indicate that the Gunflint iron formation was originally rich in pyrite. In the Lake Superior region the iron formation rocks, such as the ferrous carbonates, are known to be pyritic, and in fact this mineral is so abundant in places that the rock is essentially a mass of pyrite with minor amounts of the iron carbonate. It is easier to conceive the pyrite to be original in an iron formation of an aqueoigneous type, as the Lake Superior iron formations prevailingly are, than to be abundant in the gabbroid rocks only at a place, as in this case, where this igneous mass is intrusive into or lies upon an iron

[1] *Loc. cit.*

formation. Undoubtedly the Archean greenstones below were metamorphosed at the same time as the Gunflint iron-bearing formation, but these fail to show any pyrite in the parts studied. Had sulphur been contributed by the gabbroid rocks, then these metamorphosed greenstones ought to show a sulphur content. No doubt sulphur fumes were very abundant at the time of the intrusion, but it seems more likely that these would largely escape as sulphur dioxide rather than combine with iron to form pyrrhotite, except perhaps in a small measure. Furthermore, when pyrite is subjected to heat, the chemical composition is altered and the mineral takes on the composition of pyrrhotite.[1]

The facts enumerated are taken to indicate that the iron-bearing formation was originally rich in pyrite, and that due to regional metamorphism, heat supplied by the intrusives changed the pyrite present to pyrrhotite; sulphur fumes rose, and in a small measure perhaps combined with some of the ferrous iron available higher in the series and thus account for the presence of the small amount of the pyrrhotite in the contact phase of the intrusive mass above, though the heat of this mass itself no doubt also prevented to some extent the formation of the pyrite. There has therefore been a loss in sulphur in the iron-bearing formation rather than a gain.

From the median position of the Gunflint district, one would expect that the Gunflint iron-bearing formation originally contained not only rock types of the Mesabi but also those of the Animikie district of Canada. This location therefore suggests that the Gunflint iron-bearing formation might have been slaty in part, and this is further emphasized by the aluminous minerals now contained by the metamorphosed iron-bearing formation.

Of the aluminous minerals, the mineral cordierite, which is so very abundant, is especially referred to. This mineral has a composition, according to Iddings, as follows: silica 49.4 per cent., alumina 33.6 per cent., ferrous iron 5.3 per cent., magnesia 10.2 per cent., water 1.5 per cent. The magnesia would necessarily be provided by the ferrous carbonate rocks, but the alumina,

[1] Moissan, "Traite de Chemic Minerale," Vol. IV., Metaux, page 565.

which is low in the carbonate rock, must be accounted for as having been derived from some aluminous rock such as a slate or an aluminous schist, or else it would be necessary to assume that alumina had been introduced, which it will be pointed out to be very unlikely. Professor Lacroix[1] was the first to study the origin of cordierite, and he demonstrated clearly that the cordierite rock of Pallet is the result of absorption of an aluminous schist by a gabbro. This was shown by petrographic examination as well as by field relations and chemical analyses. It is therefore assumed that this abundance of cordierite in the Gunflint iron-bearing formation signifies that the original formation was very aluminous, due to interbedded slaty phases. The chemical analysis is very like that of the taconite except for the alumina, which is higher in the Gunflint analysis, and still not high enough to account for the cordierite determined. The slides were carefully measured so as to make the error in the calculations of the quartz and cordierite (which are often difficult to distinguish when measuring the slide) as small as possible. Allowing for errors, there would still be a deficiency in the alumina. It is therefore likely that the discrepancy is due to the lack of sufficient chemical analyses of the iron-bearing formation.

It is regarded as likely that the iron-bearing formation was not in the form of the ferruginous cherts at the time of the intrusion of the gabbro. The ferruginous cherts of the Lake Superior iron districts are of a secondary origin. In those iron-bearing formations in which the original rock was the ferrous carbonate or silicate rock, or both, the first important alteration towards the development of iron ore was the oxidation of the iron under katamorphic conditions, producing thereby the ferric silicate rocks, better known as the ferruginous cherts. Where the original formation was essentially the carbonate rock, the oxidation of the iron resulted in the banded ferruginous cherts; where the ferrous silicate (greenalite rock) was the predominating rock, there the ferruginous cherts show little or no banding. A leach-

[1] MM. Lacroix ("Les Enclaves des Roche volcanique"), Prohaska (*Sitzb. k. Akad. Wissensch.*, Wien, 1883, XVIII.).

ing of the silica from these ferruginous cherts brought about the concentration of the iron resulting in the largest part of the present ore bodies.

From the chemical point of view, therefore, the development of the cordierite-magnetite from the ferruginous cherts is unlikely because such a change would involve a reduction of the iron in the latter from the ferric to the ferrous state. This is not only an unusual state in the chemistry of the alterations of the iron-bearing formations of the Lake Superior region, but also seems improbable, for it is a far simpler process, and the more likely one, to develop the cordierite-magnetite rock directly from such rocks which contain the iron in the ferrous rather than in the ferric state. Further, the ferruginous cherts are low in magnesia, hence, had the cordierite-magnetite rock, which contains more magnesia than the ferruginous cherts, developed from the cherts, it would be necessary to assume that magnesia had been introduced, which is very unlikely, whereas the ferrous carbonate rocks contain a sufficient amount of this oxide.

Considered from a physical point of view, the textures and structures of the cordierite-magnetite rock do not correspond to those of the iron-bearing formation rocks of the other Lake Superior districts where such a formation has suffered from igneous intrusions after the iron-bearing formation had been altered from the ferrous to the ferric state, namely, to the ferruginous cherts. The Marquette[1] and the Penokee-Gogebic[2] ranges are especially referred to. In these places the original ferrous rocks of the iron-bearing formations are known to have been altered by weathering to the ferric rock, the ferruginous cherts, or soft ore jaspers, were properly exposed to oxidizing agents, and where not properly exposed, there no alteration has been accomplished. Intrusions into the iron-bearing formations have developed the hard ore jaspers and jaspilites from the softer cherts, and amphibole-magnetite rocks from the unaltered ferrous rocks. The iron-bearing formation of the Gunflint district

[1] Mon. U. S. Geological Survey, Vol. 28.
[2] Mon. U. S. Geological Survey, Vol. 19.

lacks the banded jaspers; neither is it an amphibole-magnetite rock, but one similar to it in the nature of its development, and for reasons previously stated, is distinguished by the name "cordierite-magnetite rock." It is quite evident that like geological conditions existed to a large extent throughout the metamorphic processes at the time of the development of the two different magnetite rocks, and the mineral differences now existing must be accounted for by assuming original differences in chemical and mineral composition of the iron-bearing formation.

The presence of magnetite ores in the Gunflint iron-bearing formation is taken as further evidence against the development of the cordierite-magnetite rock from any rocks or rock formations containing the ferric compounds. Van Hise[1] states that the magnetite can form directly from the iron carbonate according to several reactions. Further, that observations in the field show beyond question that the change from iron carbonate to magnetite takes place on an extensive scale. It has been shown that the Gunflint formation was originally probably very pyritic, and since the changes effecting this formation took place in the zone of anamorphism, where the conditions are reducing instead of oxidizing, it is thought probable that the following reaction is the dominant one:

$$2FeCO_3 + FeS_2 + 2H_2O = Fe_3O_4 + 2H_2S + 2CO_2.$$

The alteration of the greenalite to magnetite is possibly by the following reaction:

$$3FeSiO_3 \cdot n \cdot H_2O + O = Fe_3O_4 + 3SiO_2 + n \cdot H_2O.$$

In contrast to this it is to be noted that the ferruginous cherts and hematite ores develop from the ferrous compounds by the katamorphic processes. The banded ferruginous cherts under anamorphic conditions would develop the hard jaspers and jaspilites, it has been stated, while the hematite ores are not known

[1] "A Treatise on Metamorphism," by C. R. Van Hise, Mon. U. S. Geological Survey, Vol. 47, p. 838.

to have developed magnetite on a large scale under such conditions.

Conclusion.

The evidence at hand therefore favors the conclusion that the original rocks from which the cordierite-magnetite rock developed through the igneous intrusion into the Gunflint iron-bearing formation, are such as correspond to: (1) a cherty, pyritic, iron carbonate, and (2) a ferrous silicate rock corresponding to a great extent to the greenalite rock of the Mesabi iron-bearing formation, with (3) considerable amounts of argillaceous matter in the form of ferruginous slates.

Possible Transfer of Materials to or From Intrusives Near Contact.

It is obvious that the Keweenawan intrusives are responsible for the anamorphic alterations of the rock formations of the Gunflint district. It has long been a mooted question whether at the time of the anamorphism, the igneous mass, which then was a fluid magma, contributed liquids or gases, or abstracted or absorbed any of the chemical constituents of the rock formations with which the magma came in contact and perhaps even rendered viscous. Because of the data available, the discussion will be limited essentially to the iron-bearing formation.

The essential similarity of the analyses of the cordierite-magnetite rock of the Gunflint iron-bearing formation and the taconite of the Mesabi iron-bearing formation argues against any appreciable introduction of chemical elements. Had there been an introduction on a large scale, there would probably have resulted an entirely different proportion in the various elements than that obtained, or, if introduced and the proportions still remained unchanged, then it would be necessary to assume that the material contributed from the gabbro has been present in the latter in like proportions as those originally contained in the iron formation, and this an unlikely condition. The metamorphic effects of the gabbro extend through a very great thickness of strata, and this

seems to be further evidence that no large amounts, if any, were contributed from the gabbro mass.

An important point to note is that the diopsides and olivine of the Duluth gabbro are more or less titaniferous. The Logan sills contain various titanium-bearing minerals and fairly well developed crystals of apatite, and the iron formation contact phase contains these only for a distance of about one half foot, or less, and in smaller quantities, while the balance of the iron formation showed none of these in the microscopical examination, and the chemical analyses made from time to time during exploration work of drill cores showed extremely small percentages of titanium and phosphorus. The larger masses of magnetite in the gabbros are very titaniferous whereas the magnetite masses in the Gunflint iron formation are practically void of the same. This shows that as far as observed there has been no introduction of titanium and phosphorus in appreciable amounts.

There are practically no alkalies in the Gunflint iron-bearing formation, while in the Duluth gabbro there is 3.4 per cent. of these elements. This is taken to indicate that there has not been an introduction of these by the gabbro.

In the Gunflint iron-bearing formation the alkaline earths amount to 1.20 per cent., in the taconite to 1.00 per cent., and in the average gabbro mass to 15.60 per cent. The magnesia shown by the analysis is insufficient to account for the magnesia minerals, especially the cordierite, of the iron-bearing formation, but it will be seen from the carbonate rock analysis that the magnesia is very abundant in the unaltered rock, and would fully satisfy the required amount. These small values ranging from .50 per cent. to 1.20 per cent. for the iron formations certainly indicate that there has not been a transfer of the alkaline earths to the iron formation by the intrusive when the latter contains as much as 15.60 per cent. of the same.

The alumina of the Gunflint iron-bearing formation averages 1.20 per cent., in the taconite there is but 0.54 per cent., and in the average gabbro mass 18.10 per cent. The large development of the cordierite in the iron-bearing formation requires a larger

amount of alumina than could be obtained from the amount shown by the analysis of the iron-bearing formation. It has been pointed out on page 165 that the Gunflint iron formation was probably slatier than the Mesabi iron-bearing formation to the southwest, and less so than that of the Animikie to the northeast, making the Gunflint iron formation more aluminous than is shown by the analysis. Slates will supply the necessary amount of this element, and are favorable for the development of cordierite, as is evident from the eastern Mesabi district where the Duluth gabbro has intruded the Virginia slate formation and developed large amounts of cordierite. Further, alumina has thus far been found not to travel freely or far in metamorphic processes. It is therefore assumed that the required amount of alumina was originally contained in the iron-bearing formation.

The silica of the Gunflint iron-bearing formation averages 60.50 per cent., in the taconite 58.70 per cent., and in the average gabbro mass 48.20 per cent. The Gunflint formation appears to have the normal amount of silica as is shown by the iron-silica ratios on page 162, consequently it is doubtful if so basic a rock as this gabbro mass would be effective in introducing further amounts of silica.

The metallic iron amounted to 25.20 per cent. in the Gunflint formation, 25.70 per cent. in the Mesabi formation, and 8.60 per cent. in the gabbro mass. The exceedingly close value of the first two and the small amount in the last case make an introduction of iron highly improbable. Again, the iron-silica ratio would suffice to argue against a transfer, and further, since the gabbro magnetite is titaniferous and the iron-bearing formation magnetite is practically free from titanium, it is almost conclusive that no transfer has taken place.

The nature of the change in the sulphur content has been dealt with at length on pages 163, 164 and 165. The conclusion arrived at was that the formation was originally high in sulphur, not shown correctly at the present time by any analyses available, and that there has since most likely been a loss in sulphur rather than an introduction by the igneous intrusives.

There is no question but that the water and carbon dioxide, except for the small amount of water combined in the cordierite, have been driven from the iron formation and very likely lost to the atmosphere. It is doubtful that either one was abundant in the original formation.

It is concluded that the contact alteration of the Gunflint iron-bearing formation has been without any appreciable contribution of chemical elements from the intrusive mass, and most probably with a loss from the iron-bearing formation of only water, carbon dioxide, and sulphur.

The Present Characters of the Gunflint Iron-bearing Formation the Result of Recrystallization.

It follows from the foregoing that the condition which brought about the physical and mineralogical changes described in previous pages are presumably those of deep-seated recrystallization due to regional metamorphism and under mass static conditions. Recrystallization explains many of the perplexing problems encountered in this investigation.

Dynamic metamorphism has played little or no part. The texture of the metamorphosed rocks is prevailingly poikilitic. The crystals are xenomorphic, there is no uniformity of grain, no sign of granulation, no parallel alignment of minerals, no development of schistosity, or even undulatory extinctions. There has been a complete rearrangement of the minerals in a condensed form and the minerals now interlock or seem to have interfered with one another in crystallization. Their unusual shapes indicate that there was no room to facilitate their growth. Mass static conditions therefore prevailed.

The regular increase in specific gravity in the metamorphosed rocks over that in the unaltered rock indicates, since there is lack of evidence favoring the dynamic processes, that the metamorphism took place under great pressure, and therefore was most likely deep-seated. The presence of large masses of the Keweenawan intrusives overlying the iron-bearing formation and

the greenstones well meets the requirements for deep-seated pressure.

Sedimentary rocks facilitate recrystallization because of their high water content. The Gunflint iron-bearing formation is of a sedimentary origin and consequently certainly contained sufficient water to materially assist in the transformation which has taken place. Since the changes have been profound, the water content was probably very high. The new minerals developed are anhydrous, except the cordierite and that has but 1.0 per cent. of water in its composition. Gas and liquid inclusions are very abundant in some minerals.

Recrystallization accounts for some very strange mineral associations and rare occurrences. Some of these are: quartz included by fayalite; both are found with large amounts of cordierite. With these various minerals there are found but few others and these in small amounts only, except at the contacts with the sills where there is a great variety of minerals and most of them are in small amounts only. The quartz crystals observed were coarse and not like the fine cherty variety of the ferruginous cherts of the other ranges. The development of some of the minerals is known to extend to great depths and through an area many miles in extent. Certain minerals seem to be segregated at different horizons, as, fayalite and magnetite at the bottom of the iron-bearing formation, and pyrrhotite and quartz in the contact phases. The calcium-bearing minerals (ferro-magnesian) are found only in the contact phase of the iron-bearing formation, the calcium being nil at the bottom of the formation.

The presence of the intrusive rock suggests the fusion of the rocks with which they came in contact and also the transfer of elements by the former to the latter, but it is more likely that the Keweenawan mass merely supplied the heat to effect the metamorphic changes previously enumerated and without the fusion of the intruded rock or an absorption of constituents by the latter. Had fusion taken place, and had it been dry or aqueous, the resulting mass would have been a true magma and such mineral associations as cordierite, fayalite, magnetite and free

quartz would hardly have then resulted. It is known that under the influence of pneumatolytic agents fayalite and free quartz have been formed in certain granites[1] in Ireland, and in the lithophysæ of the rhyolites in Yellowstone Park,[2] of Lipari, and a few other places. F. G. Adams, in his experiments with limestone, has shown that a rock can be made to crystallize completely when subjected to great pressure without the aid of fusion. Original structures and textures are destroyed and new textures (metamorphic) result. Since so large a mass of rocks, as presented by this area, has been thoroughly metamorphosed and since it is well known that the Keweenawan flows were of great thickness, it seems more likely that this gabbroid mass supplied great amounts of heat to bring about the present conditions rather than to have caused the fusion of the several formations.

Had absorption by the iron-bearing formation taken place, then the analyses of the metamorphosed rocks ought to show signs thereof. It has been pointed out in previous pages that no transfers of elements from the gabbro to the iron-bearing formation were very likely, and that the latter seems to have lost only water, carbon dioxide, and sulphur, and these substances usually are delivered to the atmosphere.

It is therefore concluded that deep-seated recrystallization due to the heat supplied by the intrusive Keweenawan mass to the various formations with which it came in contact, more especially the iron-bearing formation, took place under mass-static conditions and brought about the physical, mineral, and chemical changes enumerated.

Explanation of the Tables.

The following tables show the mineral compositions of the rock formations of the Gunflint district. Each slide studied was carefully examined and the minerals thereof measured, obtaining thus the mineral volume of the slide. According to the characteristics of the mineral as observed under the microscope, a

[1] Delesse, *Bull. Soc. Geol. France*, II., X., page 571.
[2] Iddings, 7th Ann. Rept., U. S. Geol. Survey, 1888.

certain specific gravity was assigned to it; multiplying this by the per cent. of volume occupied by the mineral in the slide, the per cent. of weight was obtained. The sum of the numbers obtained by multiplying the per cent. by weight of a mineral by its specific gravity gives the mineral specific gravity of the formation in question. The specific gravity assigned to each mineral in the different rock types is also shown in the tables.

TABLE I.

MINERAL COMPOSITIONS.

Metamorphosed Greenstones (200 ft.).

Minerals.	Per Cent. Volume.	Specific Gravity.	Per Cent. Weight.
Hypersthene	33.60	3.45	39.70
Actinolite	0.49	3.00	0.51
Magnetite	0.69	5.175	1.21
Pleonaste	0.20	3.55	0.23
Biotite	2.16	2.90	2.08
Andesine-Lab	.05	2.70	0.05
Cordierite	50.65	2.60	44.50
Clinochlore	7.85	2.65	7.00
Anthophyllite	4.22	3.15	4.60
Staurolite	.01	3.71	.07
Pyrite	.03	5.02	.05
Limonite	Small	.....	Small
Zircon	"	.....	"
Epidote	"	.....	"

Mineral specific gravity, 3.015.

TABLE II.

MINERAL COMPOSITIONS.

Ore (13 ft.).

Minerals.	Per Cent. Volume.	Specific Gravity.	Per Cent. Weight.
Bronzite	3.14	3.35	2.70
Hedenbergite	3.44	3.58	3.15
Actinolite	0.19	3.15	0.15
Grünerite	2.39	3.712	2.28
Fayalite	32.40	4.10	34.20
Pyrrhotite	1.43	4.61	1.69
Magnetite	26.80	5.17	35.41
Pleonaste	0.50	3.55	0.45
Quartz	2.14	2.65	1.46
Cordierite	26.33	2.63	17.80
Bowlingite	0.65	2.56	0.44
Antigorite	0.38	2.58	0.25
Anthophyllite	0.11	3.20	0.09
Clinochlore	Trace		

Mineral specific gravity, 4.147.

TABLE III.

MINERAL COMPOSITIONS.

Iron Formation (46 ft.).

Minerals.	Per Cent. Volume.	Specific Gravity.	Per Cent. Weight.
Bronzite	12.6	3.35	11.98
Hedenbergite	9.2	3.58	9.44
Actinolite	2.5	3.10	2.20
Grünerite	0.9	3.712	0.95
Fayalite	9.2	4.10	10.69
Pyrrhotite	1.9	4.61	2.49
Magnetite	19.2	5.17	28.21
Pleonaste	0.2	3.55	0.21
Quartz	2.8	2.65	2.10
Cordierite	37.8	2.63	28.27
Anthophyllite	2.6	3.20	3.25
Bowlingite	0.2	2.65	0.15
Antigorite	0.1	2.58	0.07
Sericite (and calcite)	Trace		
Clinochlore	Trace		

Mineral specific gravity, 3.771.

TABLE IV.

MINERAL COMPOSITIONS.

Iron Formation Contacts (23½ ft.).

Minerals.	Per Cent. Volume.	Specioc Gravity.	Per Cent. Weight.
Bronzite	3.60	3.35	3.82
Hypersthene	2.47	3.50	2.74
Hedenbergite	4.00	3.50	4.46
Augite	4.46	3.33	4.74
Diallage	0.51	3.43	0.55
Diopside	2.79	3.11	2.74
Actinolite	1.82	3.15	1.79
Pargasite	1.39	3.11	1.38
Hornblende	2.92	3.33	3.10
Chrysolite	0.02	3.27	0.22
Pyrrhotite	11.18	4.61	16.34
Magnetite	3.42	5.17	5.62
Quartz	36.36	2.65	30.59
Cordierite	16.08	2.63	13.42
Antigorite	2.39	2.50	1.89
Anthophyllite	1.01	3.20	1.03
Clinochlore	2.32	2.81	2.07
Sericite (and calcite)	0.51	2.76	0.48
Biotite	2.54	3.10	2.49
Apatite	0.04	3.20	0.04
Ilmenite (rutile)	0.17	5.0	0.28
Crocidolite	0.02	3.2	0.22

Mineral specific gravity, 3.321.

TABLE V.

MINERAL COMPOSITIONS.

Logan Sills (16 ft.).

Minerals.	Per Cent. Volume.	Specific Gravity.	Per Cent. Weight.
Bronzite	1.14	3.30	1.19
Hypersthene	0.23	3.40	0.25
Augite	21.72	3.40	23.32
Diallage	0.62	3.43	0.67
Hornblende	9.75	3.11	9.60
Hyalosiderite	1.86	3.57	2.08
Pyrrhotite	1.00	4.61	1.47
Magnetite	7.07	5.17	11.61
Ab, An	26.18	2.68	22.17
Ab_2An_3	6.53	2.70	5.60
Ab, An_3 (+)	1.54	2.73	1.34
Bowlingite	0.54	2.65	0.46
Antigorite	0.57	2.50	0.45
Anthophyllite	0.13	3.20	0.13
Clinochlore	3.75	2.81	3.32
Penninite	0.36	2.65	0.30
Sericite (and calcite)	1.44	2.76	1.27
Apatite	0.15	3.20	0.15
Biotite	14.68	2.90	13.47
Ilmenite	0.69	5.00	1.10
Epidote	0.05	3.30	0.05

Mineral specific gravity, 3.322.

TABLE VI.

MINERAL COMPOSITIONS.

Duluth Gabbro.

Minerals.	Per Cent. Volume.	Specific Gravity.	Per Cent. Weight.
Diopside (titaniferous)	9.15	3.40	10.55
Hornblende	2.03	3.33	2.31
Hyalosiderite	6.10	3.57	7.38
Magnetite	5.09	5.17	8.94
Ab_1An_4	34.03	2.69	30.05
Ab_2An_4	34.03	2.69	30.95
Ab_2An_3	34.03	2.70	31.08
Bowlingite	1.78	2.65	1.60
Antigorite	1.18	2.50	0.96
Clinochlore	1.27	2.81	1.21
Penninite	2.54	2.65	2.30
Sericite	2.04	2.76	1.87
Apatite	0.51	3.20	0.55
Biotite	0.13	2.90	0.12
Epidote	0.12	3.30	0.13
Pyrite	Trace		
Titanite	Trace		

Quartz, augite, actinolite, andesine, orthoclase, hematite, calcite, mesolite, pseudomesolite, zircon, rutile, are present in variable but small quantities in the less common varieties.

Mineral specific gravity, 3.05.

TABLE VII.

MINERAL COMPOSITIONS.

Gabbro, Contact Phase (178 ft.).

Minerals.	Per Cent. Volume.	Specific Gravity.	Per Cent. Weight.
Bronzite	12.3	3.3	12.91
Hedenbergite	2.64	3.5	2.84
Augite	3.92	3.3	4.11
Chrysolite	2.11	3.27	2.19
Pyrrhotite	7.40	4.61	10.86
Magnetite	5.12	5.17	8.40
Perthite	5.71	2.60	4.72
Ab, An	28.75	2.68	24.53
Ab_3An_4	17.58	2.71	15.21
Cordierite	6.42	2.63	5.38
Antigorite	0.34	2.50	0.26
Anthophyllite	1.43	3.20	1.46
Clinochlore	0.49	2.70	0.43
Sericite	0.59	2.76	0.50
Biotite	3.15	2.70	3.00
Ilmenite (titanite)	1.90	5.00	3.02
Epidote	0.07	3.30	0.07
Zircon	0.07	4.70	0.11
Pyrite	Small		

Mineral specific gravity, 3.295.

A PECULIAR HEMATITE ORE ON THE TRACT OF THE DURHAM MINE, DURHAM, PENNA.[1]

W. S. Bayley.

The Durham iron mine is situated in Bucks County, Penna., about 1½ miles south of Easton and from ½ to 1 mile west of the Delaware River. It is one of the oldest mines in the United States and was formerly one of the most important. It was first opened in 1698, and in 1727 it furnished ore to a furnace built near the village of Durham. During the War of the Revolution, this furnace supplied much of the shot and shell used by the Continental Army.

The ore deposits are in a ridge of pre-Cambrian gneisses, which is the western extension of Musconetcong mountain in New Jersey. The geological conditions over most of the ridge are similar to those in the Highlands of New Jersey, described elsewhere. The prevailing gneiss is a phase in which potash is the predominant alkali—called the Byram gneiss in the folios of the U. S. Geological Survey. In addition, there are present layers of a soda-rich gneiss—the Losee gneiss of the U. S. Geological Survey—and others of a basic gneiss rich in iron and magnesium, known as the Pochuck gneiss. These layers are very flat lenses. The gneisses all possess an elongate or pencil structure, the pitch of which is the same as the pitch of the lenses. Moreover, many of the gneisses are schistose, in which case the dips and strikes of the structure and of the lenses are parallel. The rocks are believed to be igneous except perhaps a few of the basic gneisses which may be metamorphosed sediments, possibly limestones.

The ore bodies that have been worked by the Durham mine

[1] Read before the Geological Society of America, Washington meeting, 1911, and published with the permission of the Director of the U. S. Geol. Survey.

are divisible into two groups, one on the northeast peak of the ridge, known as Rattlesnake Hill, and the other on its southwest peak, known as Mine Hill.

The Rattlesnake Hill deposits are like those occurring in the gneisses elsewhere in the Highlands. They are essentially lenses of magnetite. An analysis by P. W. Shimer of a sample from a 2,000-ton ore-pile gave:

Fe_2O_3	FeO	Al_2O_3	MnO	MgO	CaO	K_2O	Na_2O	SiO_2	P_2O_5	S	TiO_2	H_2O	Total.
56.73	11.50	2.22	.100	.82	.16	.73	.28	25.84	.096	.105	.300	1.00	99.886

This is essentially like the analyses of the New Jersey magnetites.

The Mine Hill deposits are of two kinds. In one the ore is magnetite and so far as can be determined from the descriptions that have been published, the ore bodies are similar in character to those in Rattlesnake Hill. A sample of "blue" ore from Mine Hill analysed by G. W. Maynard was probably magnetite. The analysis is quoted in line (I.) below. The other type is unique in the character of its ore. Its main mass is hematite, as will be seen by the analysis quoted in the second line below (II.), which was made by Professor Maynard on a sample of "red" ore from the underground workings at Mine Hill. The relation of

	Fe_2O_3	FeO	Al_2O_3	MgO	CuO	K_2O	Na_2O	SiO_2	P_2O_5	S	Total.
I.	23.44	49.34	3.71	1.87	.31	tr.	tr.	21.01	tr.	.13	99.81
II.	67.57	1.53	.41	.21	.59	tr.	tr.	29.27	tr.	.24	99.82

this ore to the magnetite (analysis I.) is not known, but it is evident that, as mined, it consisted mainly of hematite and quartz, since there were present in it 96.84 per cent. of Fe_2O_3 and SiO_2 to 2.98 per cent. of all other components. In this respect it is different from all the other iron ores in the gneisses of the Highlands.

Hematite ores, it is true, occur in widely scattered areas through the Highlands but they are associated with pre-Cambrian sedimentary rocks and not with the gneisses. So far as can now be learned from the exposures they are bedded deposits, in which the ore is present to a large extent in the interstices between the grains of quartzites or conglomerates.

In the western Adirondacks (St. Lawrence and Jefferson counties), however, hematite ores have been described by Smyth and others[1] as existing in limestone and schists as lenticular bodies, composed of an amorphous, red, powdery mass of hematite containing lumps and concretions of hard specular ore. Sometimes the ore has a mammilary structure and occasionally the specular ore is micaceous.[2] These ores are regarded as being formed by the replacement of limestone through the agency of ferriferous waters that obtained their iron from decomposing pyrite in neighboring granites and schists.[3]

Another type of hematite deposit in the Adirondacks is illustrated by the Mt. Defiance Mine just south of Fort Ticonderoga, where the ore is a massive hematite filling a vertical fissure in gneiss. Mixed with the ore there is a considerable quantity of quartz and calcite. This deposit is ascribed to the circulation of underground water.[4]

It is impossible to learn now whether the ore that was called "red ore" by Professor Maynard was like any of the types of hematite occurring in the Adirondacks or not. On the surface at Mine Hill, however, there are openings that expose a hematite ore that is quite different from any ore that has been described heretofore from the Highlands or the Adirondacks. In most places this is a mixture of hematite and milky quartz that looks uncommonly like vein quartz. The hematite is scattered uniformly through the quartz as little grains up to 3 millimeters in diameter, exhibiting now and then a distinct crystal face, which often is marked by striations that suggest polysynthetic twinning. Nothing else is seen in the hand specimen nor in the thin section except an occasional smear of limonite. The quartz is granulated. Larger fragments with ragged contours are embedded in a fine-grained mosaic of quartz grains that appear to be inter-

[1] Bull. N. Y. State Museum, No. 121, 1908, p. 71–72 and 47th Ann. Rep. N. Y. State Museum, 1894, p. 692.

[2] 10th Census Report, Vol. XV., 1885, p. 141.

[3] 60th Rep. N. Y. State Museum, 1907, p. 19–20.

[4] 60th Rep. N. Y. State Museum, 1907, p. 17.

crystallized. The larger grains are crossed by strain shadows, but the small ones forming the mosaic are entirely free from all forms of optical distortion. Here and there the mosaic penetrates the larger grains as little veins. It is not probable that material of this kind was ever used as ore because of the great difficulty of separating the hematite from the quartz, and yet it is evident from the size of the holes left on the surface of the hill that considerable ore must have been obtained from some of the pits. An analysis by Dr. Shimer of a sample from 4,000 tons of ore obtained from the surface mine, which probably includes not only some material obtained from these pits, but also material from underground workings in the same or similar deposits, gave:

Fe_2O_3	FeO	Al_2O_3	MnO_2	MgO	CaO	SiO_2	TiO_2	P_2O_5	S	H_2O	Total.
61.07	5.66	.96	.10	.17	.07	30.45	.103	.06	.127	1.15	99.92

This is essentially a mixture of hematite, magnetite, limonite and quartz. Assuming that all the water present is in limonite the percentage proportions of the three constituents are: Limonite, 7.85; magnetite, 18.10; hematite, 42.24 and quartz 30.45. It is evident that the ore mined was much richer in hematite than that now exposed. That which was obtained from the surface probably occupied the holes now appearing as pits. Whether it occurred as lenses like the magnetite, cannot be stated. The quartz hematite aggregate that is now exposed constitutes a quarry wall that looks not unlike the face of a joint plane. Its general appearance suggests a huge vein mass, but since the contacts of the mass with the neighboring rocks cannot be seen its relations to these can only be surmised.

Other phases of what is believed to be the same geological mass have been found in several test pits that have been dug on the south slope of the hill on the side of the road from Monroe to Durham. These test pits are about ⅓ mile southwest of the open pits or quarries on the hill—the country between the two being covered. The ore in their dump heaps is a medium grained, gray and white rock, in some cases massive, in others slightly schistose,

and in others porous and drusy. Little irregular cavities occur here and there through the rock and from their walls project little crystals of quartz and hematite. These cavities suggest very strongly the "caves" or "pockets" in the gem-bearing pegmatites of Maine.[1] The ore is an aggregate of little grains and crystals of hematite in a white material which in some specimens is granulated milky quartz and in others is a mixture of milky quartz and a very fine-grained mass of a soft white barite. In some specimens the material is almost exclusively barite, the quartz being restricted to a few small glassy grains scattered through the finely granular white barite mass.

In the specimens characterized by a white schistose groundmass the quartz is all mosaic. Tiny veins of limonite cut through it and scattered through it are small irregular masses of the same mineral. In those specimens in which barite is an important component the sulphate occurs, mainly, as envelopes of small grains surrounding the hematite and the remains of corroded quartz grains. These latter have extremely irregular outlines and often show strain shadows.

I am indebted to Dr. D. F. McFarland, of the Chemical Department of the University of Illinois, for the analysis of a specimen of the ore containing barite. In this there were 4.77 per cent. quartz, 81.74 per cent. Fe_2O_3 and 13.80 per cent. $BaSO_4$.

The occurrence of barite in the pre-Cambrian iron ores of the Highlands region has never heretofore been reported. It has been found in association with hematite in the Parish ore bed near Fowler, N. Y., and near the village of Little York, 6 or 7 miles east of Gouverneur, in the same State. In the Parish mine, however, it occurs in little geodes in specular ore, and at Little York in a vein composed of barite, hematite, sphalerite, chalcopyrite, and calcite. Mr. Newland, to whom I am indebted for the information, writes that even at Little York the barite is uncommon.

[1] E. S. Bastin, "Geology of the Pegmatites and Associated Rocks of Maine," U. S. Geological Survey, Bulletin No. 445, Washington, 1911, p. 26–27, 82, 84, 86.

It is clear that the Durham occurrence is unique. It would be extremely interesting to know something of its relations to the vein-like mass of quartz and hematite in the quarry walls, and to the country rocks. The only suggestion concerning its origin that occurs to the writer is that the quartz-hematite mass is in the nature of a pegmatitic quartz vein and that the barite is a later introduction into the pore spaces of the original rock and along fracture cracks between the grains of its quartz mosaic and the larger quartz grains and hematite crystals. Whatever the origin of the ore, it is probable that it was not the same as that of the hematite in the pre-Cambrian sediments. The barite may have come from Newark beds, the northern contact of which, with the gneisses, is now at a fault about a mile south of the mine.

THE OCCURRENCE AND ORIGIN OF GYPSUM AND ANHYDRITE AT THE LUDWIG MINE, LYON COUNTY, NEVADA.

AUSTIN F. ROGERS.

The Ludwig mine is a copper mine of promise situated on the western slope of Singatse Ridge at the northeastern edge of Smith Valley in Lyon County, Nevada. The Wellington topographic sheet of the U. S. Geological Survey shows the location. It and the Douglas mine, half a mile distant, are the property of the Nevada-Douglas Copper Company. The writer spent a few days at these mines last August and desires to express his thanks to Mr. W. C. Orem and to Mr. S. S. Arentz, general manager and superintendent, respectively, of these properties for many courtesies. There was not time to work out the geology[1] of the mines completely but the gypsum deposit at the Ludwig mine particularly attracted my attention.

On the surface just a few feet west of the shaft of the Ludwig mine there is a prominent outcrop of white gypsum. This outcrop is about 450 feet wide and extends for a distance of about 4,000 feet in a nearly north-south direction. This linear extension, it is believed, represents the strike of a gypsum bed which, however, may not be as thick as it seems to be on the surface. The ore of the Ludwig mine occurs in a vein-like deposit 60 or 70 feet wide in altered limestone. The vein dips about 60° to the east and has a nearly north-south trend. The oxidized zone extends to a depth of about 550 feet, below which there has been some secondary sulfid enrichment of chalcocite. The hanging wall is a thinly bedded metamorphic limestone-silicate rock with

[1] The general geology of this district has been described by D. T. Smith, *Bull. Dept. of Geol., Univ. of Calif.*, Vol. 4, p. 1. Brief descriptions of these and other copper mines of the Yerington district have been given by Ransome, Bull. 380, U. S. G. S., p. 99, 1908.

garnet as the most prominent mineral. The foot wall is a gray crystalline limestone about 150 feet thick. This limestone is imperfectly bedded and on the 400-foot level the beds dip to the east at an angle of about 55°. Figure 13 is a sketch showing the relation of the ore to the surrounding rocks. Quartzite occurs west of the gypsum outcrop. As the gypsum occurs on the west side of the limestone and the ore at the surface it is presumably a bed parallel to the limestone and vein deposit with the same dip.

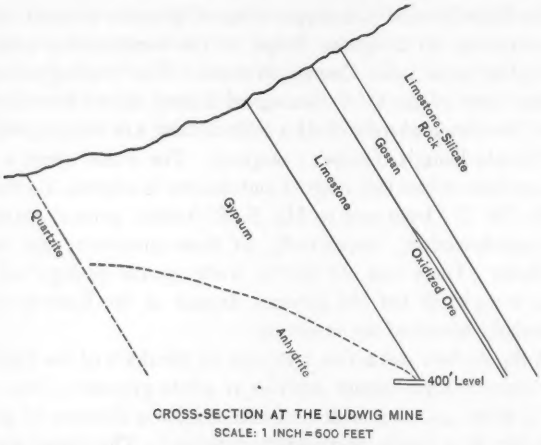


FIG. 13. Cross-section at the Ludwig Mine. (Scale: 1 inch = 300 feet.)

The gypsum is white, very pure, and of uniform quality. There are thousands of tons in sight on the surface and it is believed it extends to a depth of about 400 feet.

At present (Dec., 1911), gypsum to the amount of about a hundred tons a day is being shipped to the plaster mill of the Western Gypsum Company at Reno, Nevada. It is said to average 96 per cent. pure gypsum.

In a drift on the 400-foot level a deposit of white crystalline anhydrite was encountered. The first ten feet of this drift was in gypsum but the rest of the drift (for fifty feet) was in anhy-

drite. The anhydrite greatly resembles a pure white crystalline limestone but may be distinguished from it by the rectangular cleavage in three directions. Occasionally it shows a diagonal parting parallel to (101). The identification of the anhydrite was confirmed by the microscopic examination of crushed fragments.[1] The fragments (Fig. 14) are rectangular with bright interference colors, and parallel extinction and high relief in oil of cloves. Some fragments show diagonal twinning lamellæ parallel to (101) and an occasional parting in this direction. With dilute HCl microchemical gypsum was formed. The

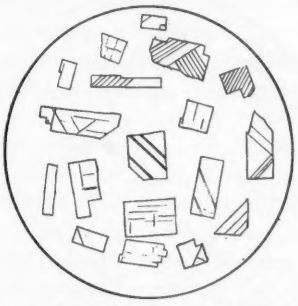


FIG. 14. Crushed fragments of anhydrite.

gypsum is almost certainly continuous from the surface to the 400-foot level. The line between the gypsum and anhydrite is probably a diagonal one as represented in figure 13. The direction of the line, however, is hypothetical and it may be irregular instead. At any rate the indications point to an immense deposit of gypsum underground as well as on the surface. A specimen taken from the contact between the gypsum and anhydrite shows a sharp line of demarcation between the two.

The interest of this deposit centers mainly around its origin. Is the gypsum formed from the anhydrite, or the anhydrite from the gypsum, or are two minerals contemporaneous? Any one of

[1] These tests furnish a better means of identification than blowpipe and chemical tests. This method was described by the author in *Sch. Mines Quar.*, Vol. 27, p. 340, 1906.

these three methods of origin is possible. The sharp line of demarcation between the anhydrite and gypsum might be interpreted as indicating contemporaneous origin. To throw some light on the relations of these minerals a thin section, showing both the anhydrite and gypsum at the point of contact, was made. Fig. 15 is a camera-lucida drawing of the thin section. The mineral marked *a* (in the lower part of the drawing) with high relief is anhydrite, while the mineral marked *g* (in the upper part of the drawing) with low relief is gypsum. Several remnants

FIG. 15. Anhydrite (*a*), gypsum (*g*).

of anhydrite (*a'*) are seen in and surrounded by the gypsum, while seams of gypsum (*g'*) penetrate the interspaces of the anhydrite. This is conclusive proof that the gypsum was formed from the anhydrite by hydration. At Bex in Switzerland the alteration of anhydrite to gypsum has taken place to a depth of 60 to 100 feet but at the Ludwig mine the alteration has reached a depth of at least 400 feet. This is probably the greatest depth on record. No dynamic effects due to hydration are apparent. It may be that the hydration has caused a running over of the gypsum on the surface, its outcrop possibly being thicker than the bed.

Having accounted for the origin of the gypsum, it remains to account for the origin of the anhydrite. Two kinds of occurrences of anhydrite are recognized. The more common is a bedded deposit formed by the evaporation of inland seas or closed basins. The Stassfurt deposit is the most prominent example of this type. The writer has described anhydrite from the salt mines of central Kansas.[1] The other type of occurrence, which is not nearly so common, is in veins or associated with ores. Lindgren has described anhydrite as a gangue mineral at the Cactus mine, Beaver County, Utah.[2] At the Rising Star mine in Shasta County, California, gypsum occurs between the ore and the country rock on the 500-foot (adit) level while anhydrite occupies the same relative position on the 1,100-foot level. Graton has proved by microscopic examination that the gypsum is an alteration product of the anhydrite.[3]

A consideration of Fig. 480 and the facts given in this paper points to the conclusion that the anhydrite is interbedded with the limestone and is the result of the evaporation of the remnant of an inland sea. It, like the limestone, has reached its present position by mountain-making forces. There seems to be no connection between the ore and the anhydrite, for a mass of limestone 150 feet thick lies between them. The occurrence of the anhydrite with the copper ores is simply a coincidence.

Two other deposits of gypsum in Nevada (Moundhouse and Lovelocks) have been described by Louderback.[4] It is quite possible that these gypsum beds have also been formed from anhydrite.

This deposit of anhydrite may be of interest in connection with the search of the United States Geological Survey for potash salts.

[1] *Am. Jour. Sci.* (4), Vol. 29, p. 258, 1910.
[2] This Jour., Vol. 5, p. 522, 1910.
[3] Bull. 430, U. S. G. S., p. 100, 1909.
[4] Bull. 223, U. S. G. S., p. 112, 1904.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

A GRAPHIC METHOD FOR DIPS ON GEOLOGIC SECTIONS.

Sir: The determination of the angle of dip of the trace of an inclined plane or bed upon a vertical plane not forming a right angle with the strike or horizontal direction of the plane or bed, is a problem familiar to all students of structural geology.

The formula in common use is,

$$\tan x = \sin a \tan y, \text{ where}$$

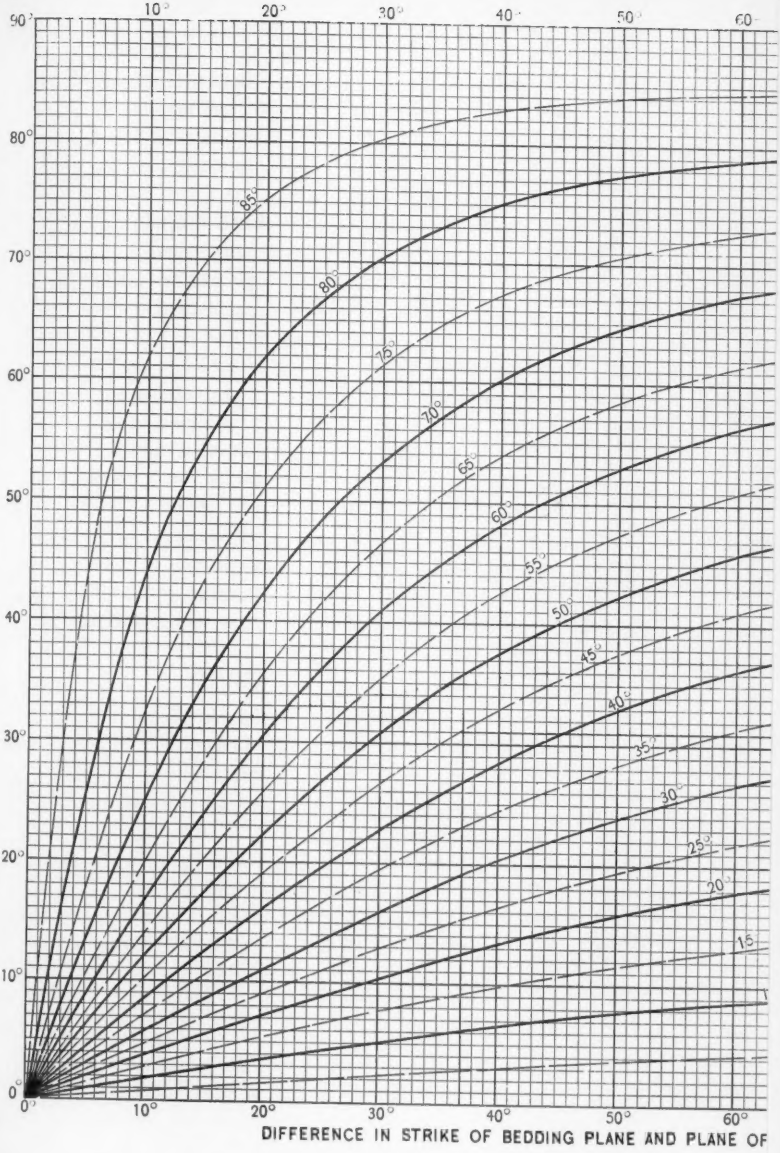
y = angle of dip from the horizontal of the given plane or bed.

a = difference between the strike of the plane or bed and the strike of the vertical plane (*i. e.*, plane of section).

x = angle of dip from the horizontal, of the trace on the vertical plane (*i. e.*, plane of section).

The necessity of making numerous cross-sections of closely-folded and faulted stratified rocks containing an ore-deposit, impressed upon me the great labor connected with the repeated use of the formula given above. It occurred to me that some sort of graphic diagram would save this labor of calculation. Numerical tables have appeared from time to time, giving the calculated results from the formula for every five degrees, but as far as I am aware, no graphic diagram has ever appeared.

A graphic method of solving the formula was adopted and the curves of the accompanying diagram (Fig. 16) are based upon


10°
20°
30°
40°
50°
60°
90°
80°
70°
60°
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40°
30°
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85°
80°
75°
70°
65°
60°
55°
50°
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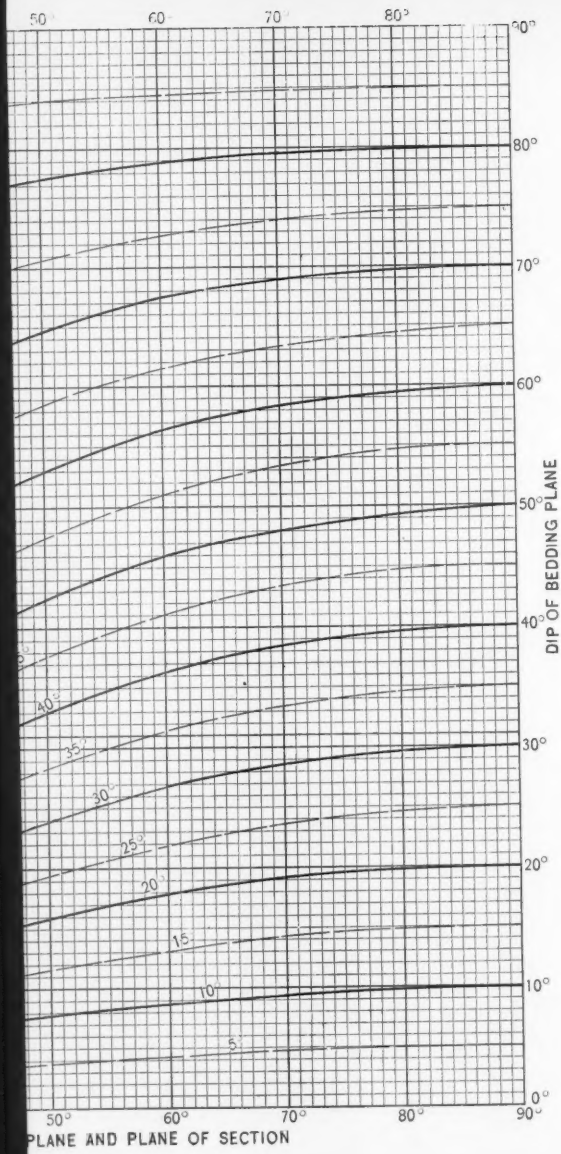
35°
30°
25°
20°
15°
DIFFERENCE IN STRIKE OF BEDDING PLANE AND PLANE OF

FIG. 16.



PLANE AND PLANE OF SECTION

numerous solutions by this method. The curves are the loci of the angles of inclination from the horizontal, of the traces on all possible vertical planes which may cut a given inclined plane.

The following solution indicates the manner of using the diagram:

Given, a plane or bed having a strike of N. 20° E. which dips 45° SE.: to find the inclination from the horizontal, of the trace of this plane or bed upon a vertical section having a strike of N. 57° E. Erect a perpendicular line from the horizontal coordinate at 37°; it will intersect the 45° curve (the angle of dip) at 31° 10′ ± 5′. This is the angle of inclination from the horizontal, of the substitute terrace on the section referred to. Solution of the problem by the use of the formula, $\tan x = \sin 37° \tan 45°$, shows x to be 31° 03′.

The error through the use of the accompanying diagram has been found to be less than twenty minutes when the difference in strike exceeds twenty degrees. Repeated use has shown a maximum error of one degree when the beds dip in excess of sixty degrees and the difference in strike is less than twenty degrees.

It is thought that such a diagram may be of general use.

D. F. HEWETT.

ORIGIN OF IRON ORES.

Sir: The explanation of the origin of the Lake Superior iron ores recently advanced by Van Hise, Leith, and Mead[1] is remarkably similar to the interpretation of the genesis of certain deposits of Devonian red hematites adopted a few years ago by European investigators. If these explanations are true, there exists a striking analogy between these two types of deposits. Since the failure to cite the European occurrences in their section on "Association of Iron-bearing Sediments and Eruptive Rocks outside of the Lake Superior Region"[2] deprived the authors of strong corroborative evidence for their present views, it has

[1] Monograph LII., U. S. G. S., 1911, "Geology of the Lake Superior Region," by C. R. Van Hise and C. K. Leith; "Lake Superior Type of Iron Ore Deposits," by C. K. Leith, in "Types of Ore Deposits," edited by H. Foster Bain, Mining and Scientific Press and Mining Magazine, 1911.

[2] Monograph LII., U. S. G. S., 1911, pp. 508–10.

seemed advisable to summarize the conditions found in the European districts in the following paragraphs.

These Devonian ores attain their greatest economic importance in the Lahn-Dill district in Nassau, Germany, where the annual production is in the neighborhood of a half million tons. Similar ores also occur in the Harz Mountains in Germany, at a number of points in Moravia, and have recently been found by J. Ahlburg[1] in the Upper Hungarian Erzgebirge. These ores wherever found possess certain marked features both as to the character of the ores and the manner of their geological occurrence. These features are very compactly summarized by Bergeat[2] as follows:

"To the most characteristic members of the middle and in part the upper Devonian east of the Rhine belong the widespread occurrences of red hematite, which almost always are found in association with diabases and schalsteins. They occur as intercalations between diabases, between schalsteins, or between diabases and schalsteins, so that sometimes the one, sometimes the other forms the hanging wall or footwall; or they occur between such rocks and limestones or shales. They possess a varying composition and structure, and frequently grade over into limestone or schalstein. When calcareous, they are called "fluxing ores"; through silicification they pass over into jaspers or ferruginous quartz. Frequently, but not extensively, the ore is specular hematite."

In order to bring out more fully the essential features of these ores, I shall discuss briefly the Lahn-Dill district both because it is the most important and because I am personally familiar with it.

The Devonian rocks in this district outcrop in two anticlines with a northeast-southwest strike, known respectively as the Lahn and Dill sub-districts, which are separated by a belt of Lower Carboniferous strata. In the northeast portion of the Dill belt, the schalsteins wedge out and at the same time an impoverishment and final disappearance of the ore beds takes place.

[1] *Zeitschrift für prak. Geol.*, 1911, p. 68.
[2] Stelzner-Bergeat, "Die Erzlagerstätten," Vol. I., 1904, p. 173.

Owing to intense folding and faulting in the district, the stratigraphic relations were long obscured, and this led to false conceptions in regard to the origin of the ores. It was formerly believed that the ore beds occurred at a number of horizons in the middle and upper Devonian, and that they represented metasomatic replacements of the limestones of those rocks. The metasomatic replacement theory was first proposed by Bischoff in 1854 in his "Lehrbuch der chemischen und physikalischen Geologie," and accepted by all subsequent workers until a few years ago. There were, however, certain grave objections to this theory, of which I can mention here only the fact that the deposits extend far below water level, and that the character of the ore differs decidedly from that formed by metasomatic replacement. It is an extremely compact red hematite and possesses the unusual property of resisting alteration to limonite even in surface outcrops. It is only where it comes into contact with decomposing sulphides, that, with the aid of the sulphuric acid thus formed, it succumbs to the influences of weathering and is altered to limonite.

Detailed work in the district, has shown that the ore occurs at a single definite horizon at the top of the middle Devonian. Underlying it are schalsteins and amygdaloidal diabases, representing submarine igneous flows. Overlying it are usually the Upper Devonian limestones. The contact of the ore with the adjacent rocks may be sharp; or it may grade on the one hand into schalstein, and on the other into limestone.

Bergeat was the first to challenge the metasomatic replacement theory of these deposits, and had E. Harbort[1] and F. Krecke[2] make a careful study of them with reference to their genesis. The solution of the stratigraphy of the district paved the way for the correct interpretation of the genesis of these deposits. The metasomatic replacement theory was no longer tenable, the asso-

[1] E. Harbort, "Zur Frage nach der Entstehung gewisser Devonischer Rotheisenerzlagerstätten," *Neues Jahrbuch für Min., Geol., und Paleon.*, 1903, Vol. I., pp. 179–191.

[2] F. Krecke, "Sind die Roteisensteinlager des nassauischen Devon primärie oder sekundäre Bildungen," *Zeit. für prak. Geol.*, 1904, pp. 348–355.

ciation of the ores and the schalsteins was unmistakable. It was but natural to look to the schalsteins, or at least to the magmas from which they originated, as the source of the iron of the ore beds. Harbort consequently advanced the theory of chemical precipitation of iron brought into the sea as a result of the igneous extrusions.

It will be impossible to go into a discussion of the reasons which led him to this conclusion, as I fear I have already transgressed the limits of these columns. Essentially the processes of ore deposition are believed to have taken place as follows: During the submarine diabase eruptions, exhalations of iron chloride vapors took place. (Sublimations of specularite as a result of the exhalation of iron chloride by active volcanoes are a common phenomenon today.) These vapors reacted with the calcium carbonate in solution or suspended in the sea water forming calcium chloride and colloidal ferric hydrate. But colloidal ferric hydrate was unstable under the prevailing conditions of temperature and pressure and in the presence of the marine salts, and was immediately converted to ferric hydrate. While this volcanic action was at its height and the iron vapors were being supplied most abundantly, little or no calcium carbonate could be precipitated, as all the available calcium would be taken up by the chlorine. Later as the exhalations decreased in amount, calcium carbonate could also be precipitated; and finally, when the exhalations ceased, pure limestone would be formed. In this way is explained the gradation of schalstein into ore, and of ore into limestone.

In comparing these two types of ore deposits, it is fully recognized that there are great differences in the physical and even chemical character of the ores, that in the one case we are concerned with highly metamorphosed pre-Cambrian rocks and in the other with far less metamorphosed Devonian strata. These differences at first glance might seem to preclude any analogy between the two types. But the analogy which I have endeavored to draw concerns the fundamental genetic processes only. The explanation of the origin of the deposits in both cases recognizes

the genetic association of the subaqueous basic extrusives, the direct contribution of the iron by the magma. Both explanations postulate a chemical precipitation of the iron from the sea water. In the case of the Devonian deposits, the relationships are far less obscured by metamorphism, and hence they afford an excellent corroboration of the fundamental principles involved.

In conclusion, attention might be called to the fact that the views now advanced in regard to the origin of these two types of deposits are in their essentials very similar to the suggested origin of the Lake Superior ores outlined some years ago by N. H. Winchell and H. V. Winchell.[1]

JOSEPH T. SINGEWALD, JR.

REPLACEMENT ORE BODIES.

Sir: The paper on "Replacement Ore Bodies," by J. D. Irving, published in the September number of ECONOMIC GEOLOGY, is valuable because it shows replacements accompanied by shrinkage are characterized by sharp boundaries.

Better proof might be had by a study of dolomites, for the reaction is simple and there is no possible doubt of the shrinkage. The process of replacement of lime by magnesia has been described in detail by Van Hise,[2] but the characteristic boundary seems to have escaped notice. This is doubtless because of the similarity of color of the minerals involved and their fine texture.

The use of the old theory that a flow of water stagnates on coming in contact with a less pervious rock should be protested. The fact is that the whole of a flow through the fissures and pores of rocks exists as an interdependent system, the pressures at any one point along the line of flow being dependent on the conditions at all other points. The inertia of the water is a negligible quantity and it cannot spread out through pores in the same manner as the jet of a hydraulic giant spreads out through air when it strikes a rock face.

[1] *American Geologist*, Vol. IV., 1889, pp. 291–300; Minn. Geol. Survey, Bull. VI., 1891, pp. 103–111.

[2] "Metamorphism," Monograph XLVII., U. S. G. S., 1904.

The pear-shape of the ore bodies which is mentioned as being characteristic would rather indicate that the flow ran from the large to the small end of the pear. The replacement would extend furthest from the fissure where the solution first comes into contact with the kind of rock it can replace. This direction of flow is the exact opposite to that which would be predicted by the old theory.

It may be only an accident, but where the sketches show volcanic rock it is in each case on the side which corresponds to the large end of the pear. Whether these be the sources or no makes little difference to the theory, however, for any geological evidence is partial and incomplete as compared with known mechanical principles.

Stated in a way which is applicable to the case in point the fact is that, neglecting the effect of inertia, a flow of water through these channels would be no more or less likely to stagnate in any particular place if the direction of flow were reversed.

The theory of solution[1] by molecular bombardment tells us that when a crystal is being dissolved or crystallized, or when it is simply in equilibrium with a saturated solution, it is shooting off molecules into the solution and is also continually having molecules project up against it from the solution. (The consideration of ionic action is not here necessary.)

If more molecules are shot off from the crystal than are attached to it, the crystal is being dissolved but if more are attached than are shot off, crystallization is going on.

With replacement, as ordinarily understood, the solution is approximately saturated but has a tendency to dissolve more soluble material in place of the less soluble substance which is being crystallized out. The molecules deposited do not, however, necessarily change positions with the molecules dissolved.

Taking this theory as a starting point the detailed action of replacement in rocks can only be explained as follows:

[1] "Theory of Solution," by Whetham (Camb. Univ. Press), chap. VII.

In the illustration (Fig. 17) let the crystal *A* be in course of formation and the substance *B* in course of dissolution. Between them there is a space containing solution. The small arrows indicate that, of all the molecules projected towards and away from the face *B* a certain balance of their number are going into the solution. The reverse applies with respect to the face *A*. The solution must be continually renovated in order that its replacement capacity shall not be exhausted. This may be either by direct pressure causing a total flow parallel to the walls *A* and *B* or by osmotic pressures causing a similar molecular flow.

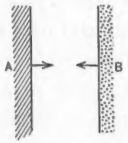


FIG. 17.

The solution on the side *B* of the channel will be more thoroughly saturated than that on the side *A*. Hence, other things being equal, the nearer *A* is to *B* the more molecules will be deposited on *A* and the more will be dissolved from *B*. On the other hand, the nearer these two walls are together the less will be the supply of new material which can be brought to the seat of action by the solution, by either direct or osmotic pressure.

These two opposite tendencies will result in fixing the width of the opening between *A* and *B*, provided that the solution is such that it will be kept approximately saturated by exchange of equal volumes of *A* for *B*. It must be understood that the saturation point varies somewhat with pressure and temperature, with the osmotic pressures tending towards replacement, and with the proximity of the crystal faces with which the solution has to come in contact. These actions all tend to facilitate replacement which is necessarily a process in which energy is dissipated. They therefore also tend toward making the channel of suitable size for a maximum rate of replacement.

If, however, the proportion of A to B (by volume) necessary to keep the solution saturated varies widely from unity, the cavity space will become larger or smaller as the case may be and the rate of replacement will thus be reduced.

Even disregarding the theory of solution it is impossible to conceive how a crystal face could be formed by replacement from a solution except on the supposition that there is a space of some kind along the face of the newly forming crystal.

It appears therefore that it is wrong to suppose that "the new mineral is substituted for the old, molecule by molecule, so that no discrepancy of space between crystal and rock grain can occur which is larger than the diameter of a single molecule."

A partial exception might be made in the case of purely chemical displacements where an atom of a molecule of the original rock is substituted by an atom or definite number of atoms from a molecule or molecules of the replacing solution. Such is the case in the dolomitization of limestone and the total number of atoms may then remain the same or some definite multiple. The same arguments apply however to crystal faces and we must suppose that the whole molecule of limestone is removed by solution and redeposited in a different place after having been transformed to a molecule of dolomite.

In Mr. Lindgren's paper, quoted by Professor Irving to illustrate the uses of molecular volume, the former adheres strictly to chemical processes and the latter seems to suggest that the argument may be used for all replacements, mentioning the case of wolframite replacing limestone. Excepting the volume criterion, which is a very unreliable one, there is much in the chemical action occurring in solutions which may be explained on purely solution theory.

The transfer of an atom instead of a molecule is in itself some criterion of replacement. For example, a carbonate in a carbonaceous rock or a sulphide in a sulphide immediately suggests replacement.

When the whole of the rock substance is replaced instead of only isolated grains of it there is not necessarily much migration of molecules. Where the numeral which goes into solution is collected from scattered points however there is every reason to believe that its molecules may travel through a considerable space before exercising their precipitating influence. When a substance is being deposited in crystalline form it does so more easily on an already established crystal face of like material. This preference makes a difference in the osmotic pressure and concentration of the solution in the vicinity of the face and molecules are accordingly drawn or forced toward it instead of forming a fresh nucleus of deposition. This action has its limitations and a balance between it and conflicting actions is fixed by the distance between crystals in course of formation.

Crystals embedded in rock and having the lamina curved about them (Fig. 95) may therefore be replacements, although involving considerable molecular migration. The flexion of the lamina may be conceived to be very easy if the surrounding rock is gradually robbed of many mineral grains or portions of grains. The purification of limestone by contact metamorphism and the simultaneous formation of garnet, etc., is suggestive of this kind of replacement.

The warping of lamina about secondary crystals is seldom or never seen in cavity fillings and it is to my mind a good criterion of replacement.

Concave Surfaces.—Concave surfaces are mentioned as typical of dissolved openings. The evidence cited only goes to prove this for air-filled openings such as natural caves with only a trickling of water in them. The case of a gypsum mine is quoted. As oxygen is necessary for the formation of gypsum it is doubtful if large masses of it can be formed under submerged conditions. In most primary ores submergence is a condition which must be reckoned on and I am inclined to believe that the concave-convex boundary would then obtain for dissolved cavities just as it would for replacement boundaries.

Temperature and Pressure.—It is not true that water (or any substance) cannot have liquid properties when above its critical temperature. The property which distinguishes a liquid from a gas is the same property (or its effect) which makes liquids capable of taking solid matter into solution, without change of temperature. A molecular replacement is therefore always evidence of solution. A gas can only make an atomic replacement or a condensation.

Replacement may therefore become a criterion whereby liquid action may be identified, as opposed to gaseous action, in deep-seated deposits: it has no connection with critical temperature. Above the critical temperature there are no very definite points dividing the liquid from the gaseous conditions but a gradual rise of temperature or diminution of pressure gradually effaces the solution properties of the liquid.

It is nevertheless important to determine approximately what the pressure and temperature conditions are in the region of this change. This may be done experimentally with some such apparatus as I have described in recent papers to the American Institute of Mining Engineers.[1] The conditions of replacement could then be spoken of as lying within measured limits of temperature and pressure.

Igneous contact growths such as garnet, tourmaline, etc., have been attributed to gaseous action. If they are replacements, as I consider them to be, they must evidently be due to a liquid carrier. They may then be confined strictly to the residual liquid products of magmatic solidification, for I have shown in the papers previously cited that all emanations from liquid magmas must be gaseous. The clumsy term "pneumatolitic" applied to these growths should be discontinued with the faulty critical temperature theory. The author is, however, to be praised on the general absence of unnecessary terms in his papers.

Many large replacement ore bodies are found separated from the igneous rock, in which their mineral matter evidently origi-

[1] "The Laws of Igneous Emanation," San Francisco meeting, October, 1911; "Physical Data of Igneous Emanation," San Francisco meeting, October, 1911.

nated, by a considerable thickness of rock similar to that which has been replaced. Many explanations of this phenomenon are possible, but the discovery of some criteria to determine which of them is correct is still wanting. Such a criterion would be a most important step in the theory of genesis of economic ore deposits.

BLAMEY STEVENS.

REVIEWS

Le Platine et les Gîtes Platinifères de L'Oural. By LOUIS DUPARC. Extrait des Archives des sciences physiques et naturelles, Vol. 31, March to June, 1911. Geneva.

This report of eighty octavo pages, is a summary of the results of twelve years of field and laboratory studies on the platinum deposits of the Urals, conducted by Professor Duparc, of the University of Geneva. It represents probably the best summary which has ever been published of the character and origin of these deposits, and is preliminary to a final report shortly to be published.

The basic rocks of the Urals form two broad belts parallel in general to the trend of the range. The western belt is the largest and most continuous and has evidently been the source of most of the commercially valuable placers. The placers associated with the eastern belt are only slightly platiniferous. The rocks of the main belt are dunites, pyroxenites, gabbros, diorites, and a large number of related varieties, to some of which special names have been given. In all of the platinum-bearing districts in this belt, the relative positions of these rocks in respect to each other are similar. The dunite forms relatively small areas, usually of oval outline, which are surrounded by a belt of pyroxenites, and these in turn are surrounded by gabbros and diorites. All of these rocks are cut by a great variety of dikes similar in composition to the types forming the stocks but showing different textures. A consideration of the chemical composition and of the distribution of these varied types of rocks shows beyond reasonable doubt that they are all genetically related and represent the successive products of magmatic differentiation. The dunite, which represents an end product of this differentiation, is greatly subordinate in amount to the less basic types. Platinum has been recognized as an original mineral only in the dunites and to a lesser extent in the pyroxenites. It was probably originally distributed in minute amounts throughout the parent magma but has been concentrated during the process of magmatic differentiation into these most basic members which crystallized last.

Careful search is necessary in order to discover platinum in its original position in these rocks. In the specimens found it occurs intercrystallized with the olivine or pyroxene, or with magnetite or chromic iron,

the association with chromic iron being particularly common. The composition of the platinum varies in the different dunite and pyroxenite areas but on the average the analyses show about 75 or 80 per cent. of platinum and 10 to 15 per cent. of iron, the remainder being copper, palladium, irridium, osmium, etc.

The amount of platinum present in these igneous rocks is not sufficient for profitable extraction. A few "schlieren" of chromic iron in the dunite do carry platinum in commercial amount, but the "schlieren" are so small and so irregularly distributed that even they can not be profitably worked.

The workable deposits are all alluvial. Their geographic position with respect to the areas of platinum-bearing rocks, as well as the presence of fragments of these rocks attached to nuggets in the gravels, shows that they were undoubtedly derived from the dunite and pyroxenite areas. The richest placers and those that have yielded the largest nuggets are in the gulches in or near the areas of platinum-bearing rocks and the yield of some of them has been fabulous. In them the platinum is usually confined to the lower 1 or 1½ meters immediately overlying the bed rock. The more distant placers in the larger streams show a covering of vegetable material (*tourbe*), then from 1 to 6 meters of barren gravels, and finally from .8 to 2½ meters of platiniferous gravel. The bed rock is usually much altered and the platinum penetrates its crevices so that it must be excavated to a depth of from 0.3 to 0.8 of a meter.

The platiniferous gravels are all of the same age, and are post-Tertiary, remains of the mammoth having been found in some of them.

There follows a brief comparison of the Ural deposits with those in other countries. All these are of minor importance, the bulk of the world's consumption of platinum, as is well known, coming from the Urals.

The paper is illustrated by thirteen black and white drawings, showing the geology of the principal areas of platiniferous igneous rocks.

EDSON S. BASTIN.

Mineralogy. By F. H. HATCH. The Macmillan Company, 66 Fifth Avenue, New York. Fourth Edition, entirely rewritten and enlarged. 124 illustrations. Price $1.40 net.

Originally written as a number of Whittaker's Library of Popular Science, this small book of 253 pages, double the size of its first edition, well serves its purpose of introducing the reader to the study of mineralogy. As in the earlier editions, the book is divided into two parts, the first of which, forming about one third, treats of the properties of minerals. These are grouped as morphological characters (dealing with crystallography), physical properties (including optical) and chemical

composition. The second half of the book is descriptive of the common minerals which are classed as: (1) Rock-forming minerals, (2) ores, (3) salts and useful minerals other than ores and (4) gems. The book is nearly free from errors both of fact and of typography and the numerous illustrations lend an added interest to the text.

WALDEMAR T. SCHALLER.

Iron Mines and Mining in New Jersey. By W. S. BAYLEY. Geological Survey of New Jersey, Vol. VII., 499 page, 23 plates, 2 maps, 31 figures.

This report aims to present all the available data on the iron mines and prospects of New Jersey, past and present. From the beginning of the eighteenth century, when mining began, to the present time, it is estimated that about 22,000,000 tons have been mined in New Jersey. The maximum production was, in 1882, nearly 1,000,000 tons. The principal factors which are pointed out as having influenced the production of New Jersey ores are, the change from charcoal to anthracite as a furnace fuel; industrial depressions, the price of No. 1 foundry pig in Philadelphia, the substitution of steel for iron, and the opening of the Lake districts. The early mines were small, and the ore, mostly bog ore and limonite, was generally reduced at the mines in charcoal furnaces. By 1854, anthracite had nearly replaced charcoal as a fuel. This change was followed by a great increase in iron ore production, subject to fluctuations controlled by the prosperity of the country and, by the price of No. 1 foundry pig in Philadelphia. Each period of industrial depression has resulted in greater centralization of mine management, and higher efficiency of operation. Mining has also become more and more restricted to the magnetites, and of these deposits only the largest or most favorably situated have remained productive. Since the New Jersey ores are better fitted for the manufacture of iron than of steel, the substitution of steel for iron, following 1882, caused the New Jersey ores to be outclassed by the Lake Superior ores, and their production declined. The present mines are the fittest which have survived a severe culling out process extending over several decades. However, with a known reserve of 35,000,000 tons of magnetite ore, New Jersey will be an important producer for a long time to come.

Formations of all ages are found in New Jersey, but the magnetite ores, which constitute the greatest present and future iron reserve of the state are found only in the pre-Cambrian. The pre-Cambrian consists essentially of three series of gneisses, sodic, potassic and basic, respectively, accompanied by pegmatites, all intrusive into still older limestone, the Franklin limestone. The magnetite ores occur mainly in the gneisses as north eastward pitching, pod-shaped, shoots, having the same struc-

tural altitude as the gneisses, and are frequently offset by cross and longitudinal faults. The ores are titaniferous, and the associated minerals are mainly basic and alkaline silicates. Some magnetite ores are also found in the Franklin limestone but in these, the shoot structure is not so evident. They are non-titaniferous and the associated minerals are mostly heavy lime-bearing silicates and calcite. Bayley designates these ores, igneous veins, derived from solutions discharged from the igneous rocks of the pre-Cambrian during their cooling.

The limonite ores are found in the Kittatinny limestone of Cambrian age, generally near the upper and lower contacts. They are believed to have resulted from the replacement of the limestone by surficial, percolating, iron-bearing solutions.

Red hematite occurs as a cement in certain clastic phases of the Franklin limestone. It has yielded very little ore.

Bog ore which was one of the principal sources of iron in the early days has developed wherever the surface conditions were favorable. The southern part of the state, which is rather swampy, has many of these deposits.

EDWARD STEIDTMAN.

SCIENTIFIC NOTES AND NEWS[1]

THE ACADEMY OF NATURAL SCIENCES of Philadelphia will celebrate its centenary anniversary March 19, 20 and 21, 1912.

DRILLING at the U. S. Geological Survey potash test near Fallon, Nev., will be resumed about March 15. It was discontinued in January on account of bad weather and other unfavorable conditions. H. S. Gale is in charge of the work.

PROFESSOR W. H. EMMONS, of the University of Minnesota, is in Washington, D. C., for the month of March.

D. W. OHERN, State Geologist of Oklahoma, was in Washington the first week in March in consultation with the officers of the Federal Survey.

D. F. HEWETT, of the U. S. Geological Survey, is in western Oklahoma making a reconnaissance geologic examination to determine the possibility of an extension of the Electra oil field, Texas, in that direction.

E. W. PARKER, Statistician of the Federal Survey, attended the meeting of the Canadian Mining Institute at Toronto, March 6–8, and of the western branch of the same institute at Vancouver, February 16–17.

A. H. PURDUE, State Geologist of Arkansas, has been appointed State Geologist of Tennessee to succeed G. H. Ashley.

DR. GEORGE H. ASHLEY, State Geologist of Tennessee, has resigned to return to a position with the U. S. Geological Survey as chairman of the Coal Land Classification Board, assuming his duties about April 1. The former chairman of the Coal Board,

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

W. R. Calvert, leaves the Survey to enter partnership relations with Arnold & Fisher, Consulting Geologists and Engineers. His headquarters will be Salt Lake City.

MR. A. A. HASSAN, of Brooklyn, expects to investigate, this summer, the supposed platinum and tin deposits in Ontario and Quebec.

AT the recent meeting of the American Institute of Mining Engineers held in New York City on February 20, J. F. Kemp was elected president of the Institute.

A. C. VEATCH, formerly of the U. S. Geological Survey, having returned from Trinidad and Venezuela, will practice as a consulting geologist, specializing in oil.

THE following papers, of interest to readers of ECONOMIC GEOLOGY, were read at recent meetings of the New York Academy of Sciences: Professor Vernon F. Marsters, "A Sketch of the Physiography and Early Mining Developments of Peru"; "Distribution of Petroleum Deposits in Peru."

AT recent meetings of the Geological Society of Washington the following papers were read: E. O. Ulrich, "Clinton Problems in the Southern Appalachians"; Reinhardt Thiesses, "On Certain Constituents and the Genesis of Coals"; Howland Bancroft, "General Remarks on Mines, Mining, etc., in Peru, Chili and Bolivia"; D. F. Hewett, "Vanadium Deposits in Peru"; D. F. McDonald and T. Wayland Vaughan, "Remarks on the Geology of the Panama Canal Zone"; Adolph Knopf, "Magmatic Sulphide Ore Body at Elkhorn, Montana"; W. H. Emmons, "The Mineral Composition of the Primary Ore as a Factor Controlling the Vertical Range of the Sulphides."

MR. WALDEMAR T. SCHALLER, chemist and mineralogist of the United States Geological Survey, is soon to leave Washington for a six months' trip to Europe where he will visit the principal mineral collections and continue his studies at the universities of Heidelberg and Munich.

ANNOUNCEMENT is made that at the University of Pittsburgh instruction in geology, paleontology and physiography will hereafter be given under the direction of the college instead of the School of Mines faculty, courses being offered in the department of geology by the following-named professors and instructors: Drs. C. R. Eastman (chairman), A. E. Ortmann, O. E. Jennings and Messrs. H. N. Eaton and Earl Douglass.

THE University of Michigan has granted a leave of absence to Professor William H. Hobbs for the academic year 1912–13. In his absence from the university, the charge of the department of geology will devolve upon Professor E. C. Case. Professor Hobb's classes in geology will be conducted by Professor Frank Carney, head of the department of geology at Denison University. Professor Hobbs will devote the year to study and travel abroad.

$12,500 was recently turned over to the authorities of the Colorado School of Mines for the equipment of the new ore testing plant. The building for the plant was built a year ago and $50,000 was allowed by the legislature for the necessary machinery and one fourth of this is what is now available. Many donations of machinery have been made by the various manufacturers and it will now be possible to completely equip, ready for operation, the concentration section of the plant.